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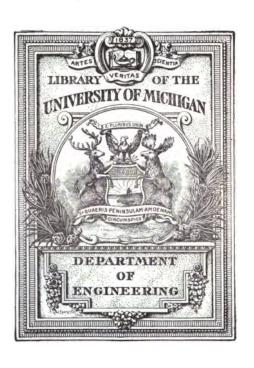
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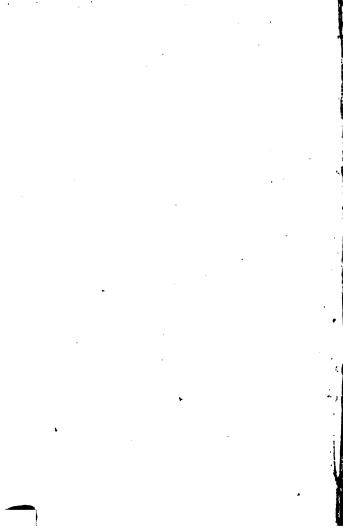
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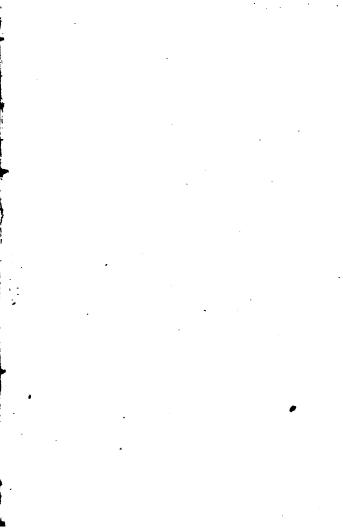
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GUIDE FOR TESTING STEAM ENGINES.

1.086

Indicators and Brakes.

Translated from the French

OF _{ほうしど}ン J. BUCHETTI,

BY

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PREFACE.

The questions relating to the testing of steam engines and the economical production of steam, are acquiring from day to day a greater importance both to the builder and the manufacturer. In the contracts for construction it is frequently stipulated that the consumption of fuel shall not exceed a stated quantity per horse power; but it seldom goes so far as to limit it to the effective or indicated power of the machine.

But after the tests for acceptance have been made, the manufacturer seldom bothers himself about the consumption in every-day work. These primary tests for consumption can only bring themselves to the level of commercial utility, by giving a thorough understanding of the various appliances that are designed to perform this work, and the several methods of using them.

(8)

The renowned Watt, who really invented the steam engine, also invented the indicator by which its action could be studied; and Richards, by improving the apparatus, has made it applicable to engines of high speed and great initial pressures. This has been followed by the construction of registering indicators giving the variatiors in the work performed during a longer or shorter period; and at last totalizers have been made that give by a reading and a simple calculation the total amount of work performed.

It is this class of apparatus that is so little known that will be taken up and described. In the first place, their construction and functions will be described; then an analysis of the diagrams will be made, and the amount of work indicated deduced. And in order that this analysis may be as complete as possible, the properties of steam will be considered.

Passing then to the mensuration of the effective work, the various constructions of the Prony brake will be described, as well

as the arrangements for automatic registration.

Dynamometers will be, to a great extent, neglected, because they cannot be applied directly to the motor and can be successfully used on small forces only.

The work will be continued by tests of the evaporative efficiency of boilers, which are frequently neglected in the specifications. And at this point, the subject of fuels will be considered.

And finally, there will be an examination of the proportions of the apparatus that is employed in evaporation, with a comparison of the various arrangements, and the whole will be concluded by the dimensions, in succession, of those types of boilers that are in most common use.



INDICATORS AND BRAKES.

THE WATT INDICATOR.

The apparatus illustrated in Figs. 1 and 2 from Tredgold is made of a small bronze cylinder from 1½" to 2" in diameter, in which there is a piston also made of bronze, and which is surmounted by a steel spring.

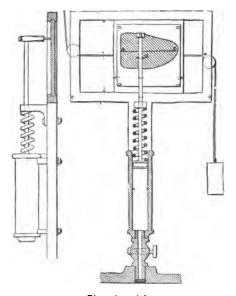
The piston rod runs through a guide and is capped by a pencil holder that is furnished with an internal spring that holds the pencil against a light board that may be covered if desired, with a sheet of paper.

This board, placed in a fixed framework, receives, by means of a cord and a counterweight, a movement to and fro proportional to the stroke of the engine piston.

The cock, which connects the instrument to the cylinder, being closed, and the pencil accordingly fixed, it will draw upon the board a line a e corresponding to the atmospheric pressure which exists upon each side of the indicator piston.

If now, the cock is opened, the piston

will rise during the admission of the steam, and compress the spring proportionally to



Figs. 1 and 2.

the pressure of the steam; then, during the escape, on the return of the board, the piston will drop below a e, elongating the spring if the engine has a condenser. For

each complete revolution of the engine, the pancil will trace a closed curve, shown in the diagram, whose abscisse or horizontal distances are proportional to the positions of the engine piston in its stroke, and with ordinates or vertical distances proportional to the pressure of steam at each point of the stroke.

The surface of the diagram indicates the work developed during a single stroke of the engine. Each part of this curve will be examined later on.

MACNAUGHT INDICATOR.

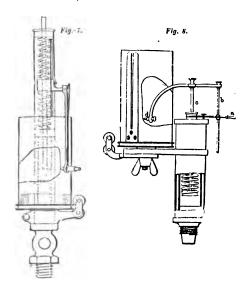
MacNaught replaced Watt's board by a rotating drum, furnished with a coil spring upon the inside.

By removing the pieces Mand N, of which we will speak later on, Figs. 3 and 4 represent this indicator as constructed by M. P. Garnier.

The indicator is attached to the cock underneath by means of the union with right and left threads, which facilitates the adjustment of the instrument.

The pencil holder h is articulated to the piece k that is fastened to the piston rod, and the pencil is held against the paper by the spring h. We see that it is not easy to regulate the pressure of the pencil or re-

move it while the instrument is at work, when this contrivance is used.



The cord which transmits the movement or the engine piston is wound about the pulley P, which is larger or smaller according to the stroke of the engine, while one wrapped about its shaft gives motion to the drum, the stroke of which is thus reduced in the proportion of the diameters of the pulley and shaft to each other.

HOPKINSON INDICATOR.

In Fig. 7, the cylinder is placed inside of the drum. The piston is surmounted by two springs that always work under compression; one for steam pressures that are above the atmospheric, the other for those that are below. Then going back to Mac-Naught's arrangement, Hopkinson modified the pencil holder so that it could be adjusted, Fig. 8. The pencil d is carried by a movable bar which has a rod b traveling through the lever a. This lever can be turned about the piston rod c, so that the pencil may be brought up to or removed from the paper at will, even while in motion. It may then be fastened in this position by a light thumb screw.

These indicators in which the pencil is attached directly to the piston, will give satisfactory diagrams upon engines running at slow speeds with a low steam pressure, as obtained with those built by Watt; but upon engines of high pressure and great speed the inertia of the moving pieces, added to the vibrations and transverse bending of the springs, prevents the pencil from following a path in true proportions

to the existing pressure. It vibriates about the point of equilibrium, and diagrams like

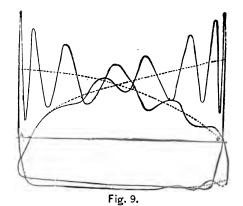


Fig. 9 are obtained, which do not permit the experimenter to judge accurately of the distribution. It is for this reason that these indicators have been abandoned. We thus come naturally to those arrangements that are made for counteracting the effects of this inertia

ARRANGEMENTS FOR OVERCOMING INERTIA.

M. Deprez placed two pieces i i upon the piston d, (Figs. 3, 4), allowing between them and the clip l the play y, which con-

stitutes the free motion of the piston. The clip l may be moved by turning the screw M N. Suppose that the pencil is up, the spring compressed and the apparatus in motion. If then we turn the screw so as to cause the pencil to descend, it will trace upon the paper a series of spirals if its movement is continuous, or horizontal lines if its movement is rapid and intermittent.

But in causing the pencil to descend the spring is extended, and its tension will soon be placed in equilibrium with that of the steam; the piston will then be displaced through the play y, and the pencil will mark a break at each step which will denote one of the elements of the diagram.

By continuing this we will obtain the successive elements which will constitute the average diagram of a certain number of revolutions.

The same result may be obtained by beginning at the bottom.

In order to obtain the same result M. Hirn places (Fig. 5, 6), a screw at the top; a stirrup b, guided by the rods a a, receives in slots upon its feet the pin which is placed at the end of the piston d, whose free movement is still y, and which is operated in the

same manner as the arrangement of M. Deprez.

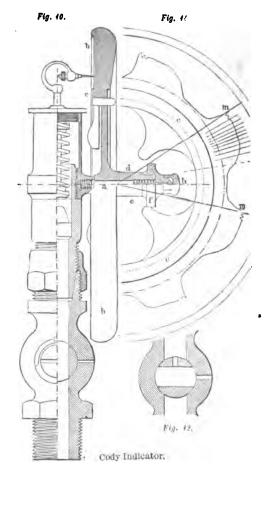
CODY INDICATOR.

This apparatus has been designed for use upon engines making 300 or more revolutions per minute, the lightness of the moving parts permitting 1,000 strokes of the piston per minute to be obtained.

The disk b running upon the shaft a carries the paper which is cut in the form of a circle, and is held in position by a groove in b and the circle c furnished with sharp hooks. The spring e abuts at one end upon the center or hub d and at the other against the movable button h.

The position of the apparatus is of no importance, provided that the shaft α does not incline so much from a horizontal position that the disk will slip off by its own weight.

To manipulate this indicator, we first heat the cylinder, then close the cock, and give the disk a whirl by taking hold of the button f with the thumb and middle finger, at the same time pressing upon h with the index finger; then as the paper is brought against the pencil the atmospheric line is drawn. This done, the cock is again opened, and a new impulse given to the disk,



that it will make about one-tenth as many revolutions per minute as the engine; we press up h for a moment and we obtain ten continuous curves as shown in Fig. 11, the back pressure curve following that of the pressure. In order to determine what belongs to a single half stroke, radii are drawn from the highest points m m of the curve and the intermediate space divided into two equal parts; then, by means of a piece of tracing paper, the second portion of the curve is turned under the first, and an enclosed polar diagram is obtained. Iu this case, the rotatory motion of the disk may be considered as constant during the short space of time that is occupied in tracing the curve.

The arc corresponding to one curve is proportional to the circumference described by the crank pin, so that in order to obtain the pressure corresponding to each point in the stroke of the piston, it is necessary to make a diagram showing the relation existing between the stroke of the piston and the crank pin (a relationship dependent upon the length of the connecting roa), then divide the arc proportionally to these paths and draw a radius to each point. These polar ordinates give the pressure desired.

This instrument has not been very extensively used, for the reading and calculation of the diagrams is a far more laborious piece of work than it is with those taken on the ordinary indicator.

INDICATORS WITH AN AMPLIFIED PENCIL MOVEMENT.

THE RICHARDS INDICATOR.

This apparatus (Fig. 13) embodies some important improvements over those heretofore described, by which it is possible to
use it upon engines working at a high pressure and speed. The stroke of the piston
has been reduced to about three-fourths of
an inch, and then the stroke of the pencil is
increased by means of a lever, in the ratio
of about one to four, in order that ordinate
of sufficient length may be obtained. The
pencil, which is placed in the center of one
of the cross bars of a parallelogram, has
a stroke that is practically straight within
the limits of its possible stroke that is utilized.

The light weight of the moving parts renders their inertia very weak, in spite of their multiplication of the stroke of the piston, which last also tends to magnify the piston's vibrations.

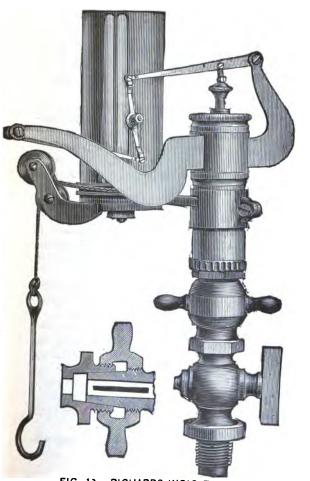


FIG. 13.—RICHARDS INDICATOR

This instrument should be constructed with the greatest care, in order that there may be no play, or any abnormal friction in the joints.

The bracket which carries the parallelogram, and the cap on the end of the piston rod, are movable about the same axis, thus permitting the pencil to be removed from the paper, even while the piston is acting; this removal being stopped by a stud.

A ring under the paper drum carries two pulleys which serve to guide the cord in any direction. The drum is attached to the cord pulley and also to a coil spring, and carries the paper which is fastened by means of a clip.

The holes above the piston in the cylinder head give communication with the atmosphere and serve as a means of cleaning.

This indicator is further furnished with the Darkee detent, by means of which the drum may be stopped for changing the paper without detaching the cord. For this purpose, the upper edge of the cord pulley is partially toothed. A pawl can be pressed against this and held away according to the position of the knob on its spring.

In the first case, the pawl will engage with

the teeth and hold the drum when it has reached the end of its throw.

THOMPSON OR AMERICAN INDICATOR.

The parallelogram, which is simpler then

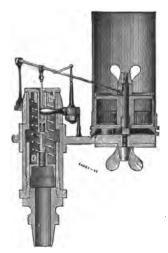


FIG. 14. THE THOMPSON INDICATOR.

the one just described, conduces to less weight in the moving pieces. Fig. 16 represents the apparatus as made by the American Steam Gauge Co. of Boston, Mass. The piston rod is of steel, made

hollow with thin walls, and runs through a guide in the cylinder head. The connecting rod, also of steel, is attached by means of a ball joint; the remaining features of the construction being the same as that already described.

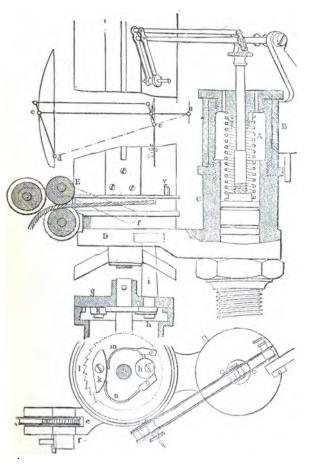
The cover of the paper drum is attached to the spring at about the center of the drum, and is loose upon the stud. In order to change the tension of the spring it is only necessary to turn this cover, tighten the upper nut, and it will be fastened to the sleeve, just as the spring is fastened to the central stud. Fig. 14 represents a perspective view of the indicator.

CASARTELLI INDICATOR.

In the amplifying movement, the lever b c is parallel to c d (Figs. 15 and 16) and in order that the pencil should travel in a straight line it is necessary that

$$\frac{ab}{ac} = \frac{ae}{ad}$$

The extension piece A which carries the movable bracket B, is screwed upon the the cylinder C, the latter being cast solid with the main casting D. This arrangement facilitates the changing of the spring and cleaning the cylinder.



FIGS. 15 and 16.—CASARTELLI INDICATOR.

The paper drum is stopped for changing papers by means of eccentric e acting upon the cord; and is brought into action by turning the handle f. Just as the cord starts back under the action of the spring, it is caught and held between the eccentric and the lower pulley, so that the drum is held fast with the spring under tension.

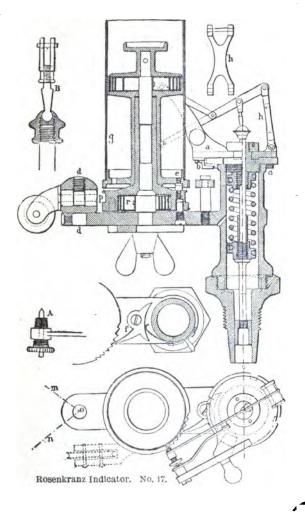
Fig. 16 represents another detent arrangement. Upon the drum cover g a pawl k is placed, which may be held away from or against the interior ratchet l by means of a button i and an eccentric h, which bring one or the other of the springs m or n into play.

THE SWEET INDICATOR.

The lever amplifier traces the diagram itself. The rotating drum is replaced by a concave plate which carries the paper. This plate, running in guides, receives a reciprocating motion from the piston, the same as the board of the Watt indicator.

ROSENKRANZ INDICATOR.

The parallelogram is of the same type as that of the Thompson indicator with a short lever, and is supported by a removable bracket a upon the cylinder head. The movement for taking the pencil away from



and bringing it up to the paper is limited by the lug b and the two studs c. The drum cord is guided by a Stanek pulley mounted upon a movable piece, d, which allows the operator to lead off the cord any direction, either om or on (Fig. 18); and consequently to turn the drum in either direction according as the indicator is placed in front or behind the cylinder.

The construction of the drum is such that its movement can be stopped with out detaching the cord. For this purpose the pulley p furnished with a spring r, is independent of the drum g, to which it is attached by means of a set screw e. So that when the drum reaches the end of its throw it is stopped by the pawl f and the pulley continues its alternating movement with the cord always stretched out to its full length.

In the Figs. A, B, h shows the detail of the pencil holder and the lever which supports h.

ARRANGEMENTS FOR HIGH PRESSURE.

Inasmuch as when it is required to take upon apparatus working under high pressure, it is necessary to resort to special springs, and furthermore as their verification is very difficult, Mr. Reidler has proposed to proportion the piston section, in the cases which may arise, to the pressure which is to be exerted and thus

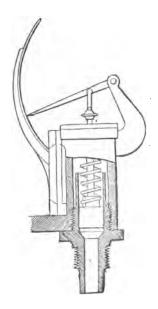


FIG. 17.

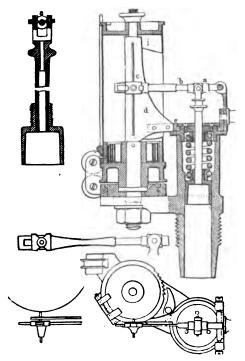
do away with the use of special springs adapted to each individual change of pressure.

We can thus with the same series of ordinary springs measure very high pressures. This arrangement is applicable to almost all the apparatus which has been described, is represented in Fig. 17. The lower tube is in the form of a small cylinder, and the small piston is surmounted by means of a special piston rod by the ordinary springs. Suppose then that we have four springs corresponding to the pressure of from four to thirty lbs.; if an instrument whose piston diameter is three-fourths of an inch, the following table will show the pressure which we can measure with two small pistons, one half an inch and the other one-quarter of an inch in diameter:

Diameter of pistons			: % in.	% in. i to % 8 20	1 to 1/2
			. 4		
	46	"	. 16	82	64
•6	46	"	. 30	60	10

DARKE INDICATOR.

This apparatus has been designed for engines of high pressure and great speed. The diameter of the piston is half an inch, its travel from ½" to ½", and the diagrams have a height of 1½" by length of 3½". The piston rod is hollow, and is terminated by



THE DARKE INDICATOR. FIG. 19.

a swivel cap which carries a spade handle joint a, oscillating upon two pivots.

Through this spade handle the increasing lever b passes with very little friction. Its extremity is flat and flexible, and it carries the grooved piece c, which in turn carries a tracer that is guided by and runs in the slot of the plate d, which is solidly attached to the turning ring e, that is in turn attached to the cylinder head. The displacement of this ring gives the method of pressing the tracer up to or separating it from the paper.

The drum is furnished with a Darke detent and contains a roll of paper. After each diagram is taken, a new quantity of paper is unrolled by hand, which is retained in place by means of two hinged strips of plate metal furnished with a catch at the upper end.

RAE INDICATOR.

M. Bourdon made, with his well-known flexible tube, an indicator, the model of which is now in preservation in the Conservatory in Paris.

Mr. Kenyon, taking up this idea, combined the Bourdon tube with the Richards parallelogram, and produced the indicator which has been so long known by his name. This has been further developed by the introduction of a new parallel motion by Mr. Rae, as shown in the indicator, Figure 20, of our illustration. The throw of the spring is multiplied in the ratio of about



RAE INDICATOR. FIG. 20.

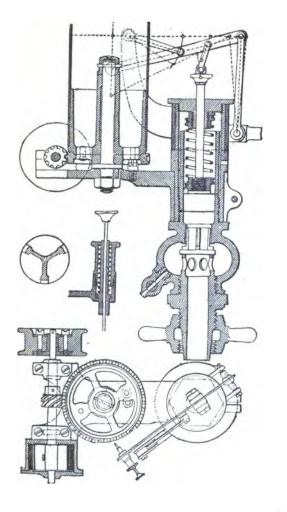
one to five, according to the pressure under which it is operated, or according as a tube of greater or less flexibility is supplied. The method of keeping the diagram of the same height belongs to the later inventions of Mr. Rae, and is obtained by adjusting the connecting rod running from the point of the spring down to the link which is hinged on the base plate of the drum. This construction does away, in the first place, with the friction of the piston and the spring, which often proves of so much injury to the delicacy of the diagram, and in the second place, the throwing out of the hot water which so greatly incommodes the operator and frequently wets and tears the paper, is also avoided.

The drum is clamped to a pulley, from which it is, in itself, independent, but by which it is carried through the means of a slight spur. It can be immediately separated from the pulley by raising it by means of a forked lever, through the agency of a cam and a small handle which are placed in position for accomplishing the purpose.

When the pulley alone continues each alternating movement, and the cord remains always in a state of tension, the verification of the scale of the flexions of the tube should be made only with steam or hydraulic pressure.

MARTIN-GARNIER INDICATOR.

The first point which distinguishes this apparatus from those which preceded it is



the control of the drum, which is obtained by means of a pinion and a small spiral toothed wheel. The arbor of the pinion carries the recoil-spring at one end, which is fastened to a small barrel, and at the other end a light pulley which is changed according to the stroke of the engine, upon which it is used. This arrangement, then, constitutes the system of reducing motion. It has, therefore, the advantage of protecting the drum from the effect of high speed and guaranteeing an exactness in the length of the diagrams, which would not otherwise be attainable.

The second point is the addition of the pulley which is placed under the cylinder, and is raised by a sudden action of the steam.

It then partially closes the passage of the cylinder, and this protects the piston against a too sudden action, and does away with the equally sudden darting out of piston and pencil, which frequently occurs. The effect of this valve is only really sensible when it is used upon engines running at high speeds.

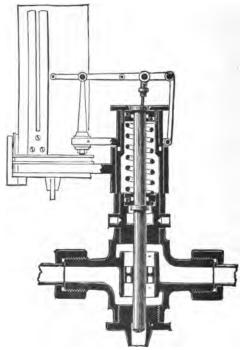
THE SCHAEFFER AND BUDENBERG DIFFEREN-TIAL INDICATOR,

The diagrams obtained with the indica-

tors which we have thus far described, give the average pressure upon one face of the piston, and take it for granted that the pressure upon the other face is exactly the same. This hypothesis is never true, for the obliquity of the connecting rod causes a difference in the distribution, and in the velocity of the piston in its forward and backward stroke, which increases as the ratio between the length of the connecting rod and crank pin grows less.

It is necessary, then, in order that the total work should be exactly represented, to take diagrams at the same time with two indicators from the front and back ends of the cylinder. From this a true diagram can be obtained for each face and at each stroke, by taking the upper curve of the outward stroke, for example, and tracing below it the lower curve of the diagram, which is obtained on the same stroke from the back end of the cylinder.

Or better still, by taking the back pressure b from the opposite pressure b', and transferring that of c over to c', we will then have as a final result the true diagram shown in Fig. 24 by that portion of the figure which is covered with hatched lines.

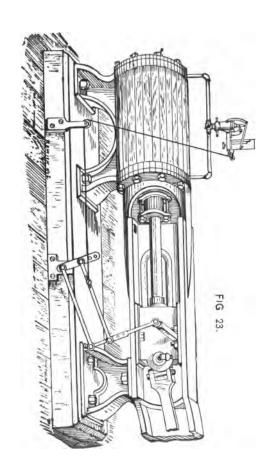


DIFFERENTIAL INDICATOR. FIG, 22.

The double or differential indicator which is shown in Fig. 22 gives precisely this same true diagram.

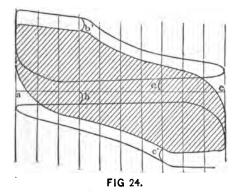
Each face of the piston of the indicator, Fig. 22, is put in connection with an end of the driving cylinder of the engine. The piston is then raised or lowered on each stroke in exact proportion to the difference of pressures which exist in the two ends of the cylinder. According to this con struction we see that the spring is always under a state of tension, and the diagram that is obtained is similar to that of Fig. 24. which is the combination of the true diagrams from the front and back ends, which represent the total work per revolution. The ordinates comprised between the curves represent the real pressure which acts upon the piston.

In establishing the communication of the indicator separately with one and then with the other end of the cylinder, we obtain two ordinary diagrams such as are traced in our Fig. 24. The apparatus can be easily made into the ordinary indicator by blocking up the hole on the left, and replacing the plug at the bottom by a tube with a screw which is fitted to receive a cock; but, under these circumstances, a



lower diagram than the ordinary one is obtained, on account of the pencil holder being always in a horizontal position at the atmospheric pressure

This true diagram will not be as useful as the ordinary one, for it does not allow us



to judge of the distribution between the different lines, since those of admission, cutoff, back pressure, and compression which we will look into farther on, are badly deformed by their fusion into each other.

The value of the true diagram to give the work performed on each face of the piston for one stroke, does not appear of very great importance to us, because if the engine is running regularly, by successively taking ordinary diagrams every purpose will be answered. If, on the other hand, the running is irregular, it will be necessary, even with a double indicator, to take several diagrams during the test, in order that the mean work may be computed.

When the apparatus is used as a double indicator, its indications are independent of atmospheric pressure. This is a very slight advantage on account of the weak variations of this pressure. It diminishes also in proportion as the scale of flexion of the spring employed grows less.

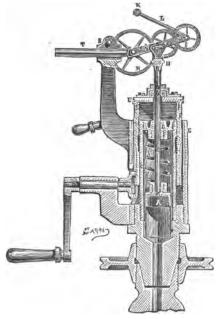
DUPREZ INDICATOR.

Duprez has applied the principle of his indicator, which we have already noted, to an indicator with amplified movement.

The piston A is surmounted by spring X, fixed to the cover G of the cylinder C. This cylinder, with an exterior screw thread, takes the tube F, which has an interior thread. The exterior surface of this tube F carries longitudinal teeth which mesh in with the gear on the shaft D. In turning this wheel to the right or left, we will cause the tube F to rise or fall.

At the head of this tube the casing a is

bolted, which is fitted on the tube with the block b surmounting the piston rod.



DUPREZ INDICATOR. FIG. 25.

The collar d is pinned to the piston rod, and its stroke is limited by the play c, which

can be reduced or altogether annulled by means of the screw plug b.

If the collar d is unpinned from the piston rod, the indicator will act in the same manner as the ordinary one and give an entire diagram at each stroke of the engine. If, on the other hand, this collar is pinned to the rod, there will be at each stroke only one element of the diagram given, and the latter will only be completed by moving the tube F from the top to the bottom of its stroke, or inversely, as we have already seen in the case of the Deprez-Garnier Indicator.

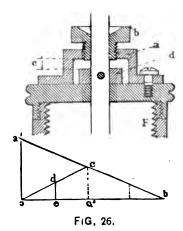
AMPLIFYING MOVEMENT.

The head H is fixed by a pin to the lever M, upon which are mounted three gear wheels. The axis of the last wheel carries the lever L, which in turn has the pencil carrier K upon it. This latter traces a vertical rectilinear line.

The principle on which this machine acts is that, given the co-ordinates o b and o a (Fig. 26) drawn from the extremities of the line a b, the point c being the middle of the line a b.

$$oc=\frac{ab}{2}.$$

The two triangles thus formed are isosceles, whatever may be the position of ab, and the angle aco = 2cob. Inversely, in a system composed of two straight lines, ac = co, articulated at c and o, but always



maintaining the conditions of a c o = 2 c o b. The point a will then describe a right line a o, perpendicular to the base b o. This result is obtained by means of the three toothed wheels; the one R (Fig. 25) is fixed; the other two, with a diameter

of one-half of R, are movable and attached to the rod M, which is articulated upon the axis of R, which is the point o of Fig. 27. The lever L=ac turns with the last wheel, and thus we always have aco=2cob.

If the piston rod is articulated at d and de is its stroke.

$$\frac{ao}{de} = \frac{ab}{od} = \frac{2co}{od} = 2K,$$

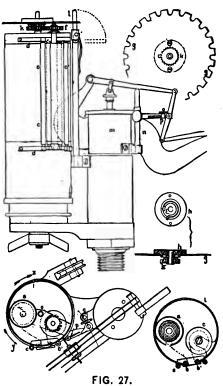
if o d is a fraction K of o c.

The ratio of its increase is then constant and its value depends upon the position of the point d on the rod o c.

The lever M has three holes for taking the pin d, which correspond to an increase of four, six and eight times the stroke of the piston.

This instrument has not received a very extensive application.

Duprez and Napoli have combined this principle to differential indicators with an electric apparatus with a pen attachment which, since the steam holds the piston in a state of equilibrium in regard to tension, is variable by hand, and makes a point of the diagram upon a movable table, which is moved to and fro synchronously with the movement of the piston.



It is thus possible to take diagrams of the running of the trains at some distance from the engine, on a special car provided for the purpose.

This apparatus has an importance outside of the object which we have laid down as the limits of this work, and for which the simple indicator is sufficient, even upon lecomotives.

RICHARDSON INDICATOR.

In this apparatus (Fig. 27) the cylinder and parallelogram are taken from the Richards movement. The swivel m carries the support n of the pencil p which traces the atmospheric line. The drum contains a roll of paper, as well as the mechanism for rolling it up, which operates during onehalf of the tracing of the diagram, as will be seen. The paper is placed in the small split center a and passing out between the rolls bc makes a turn about the drum band then enters between the rolls c'b' and is brought about and fastened to the shaft or arbor e. The rolls c c' are pressed against the paper by the springs d d', which hold it in tension upon the drum.

The arbor e carries a toothed wheel f, above which is placed a spring which acts as a brake and prevents the arbor e from

turning. This toothed wheel f meshes in with the wheel k and carries upon its axis the disk g h, which is furnished with a crown toothed wheel and ratchet. The disk q which is notched upon its circumference, carries at its center a washer h which in turn holds its ratchet up to the spring. If now the disk g is held fixed by the movable finger l, and the drum t is turned in the direction of the arrow x, the wheel fturning about the wheel k which is held fast by the spring already referred to upon the washer h, will be obliged to turn about it, consequently it will roll upon its axis e a certain length of paper C, which will add itself to the throw of the drum t. The pencil will then trace one-half of the diagram of the length A, Fig. 28. On the return stroke (y) the wheel f, held by its brake, will carry the wheel k along with it. since the ratchet allows it to turn in this direction. The paper then remains immovable upon the drum, and the pencil then traces the second half of the diagram B. The diagram thus traced will correspond to a complete revolution of the engine.

Fig. 28 shows that, according to the position of the indicator upon the engine,

the length A will belong to the admission or exhaust side, and inversely for B. In the first case, the ratio of the detent equals $\frac{a}{A}$, and that of compression equals $\frac{b}{B}$; in the second case, the ratios of $\frac{a}{B}$

2 = Cas

FIG. 28.

 $\frac{b}{A}$. We see that in order to obtain the ordinary close diagram, it will be necessary that A and B should have the same length and b becomes b', so that in the first case $\frac{b}{A} = \frac{b'}{A}$, and in the second case $\frac{b}{A} = \frac{b'}{B}$.

The compression curves thus rectified are shown by the dotted lines, and the exact degree is represented by the short hatched curves.

We can also, in the second case, rectify the upper curve without modifying the

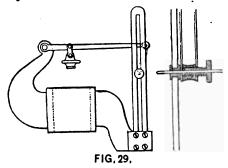
compression by taking
$$\frac{a}{A} = \frac{a}{B}$$
. The exact

diagram is then represented by a full hatched surface. The rectified compression curves show that in calculating a series of diagrams which have not been rectified, there is an error of too much in the first case, and of too little in the second, but when the compression is very slight, b differs so little from b' that the error may be neglected without any detriment. It is sufficient that we have pointed out how it is produced in each case, so that the experimenter may understand how to appreciate and adjust it.

RICHARDSON GUIDE.

Richardson has proposed a guide (Fig. 29) which could be easily adapted to the Richards apparatus by cutting off the large fixed arm. The lever attached to the piston rod ends in a small pin which carries the pencil. This latter also carries a small pulley,

which is guided along by the rectilinear conductor attached to the apparatus. This arrangement reduces the weight of the movable pieces, but creates a small amount of rolling friction, so that it has been used but very little.



SCHAEFFER & BUDENBERG VERTICAL DRUM MOVEMENT.

In this apparatus, the paper can at the will of the operator, be automatically raised at each revolution of the engine a small amount, so that a series of superimposed diagrams may be obtained. The mechanism by which this result is obtained is shown in Fig. 30. The fixed axis A carries at the upper extremity of the small spring

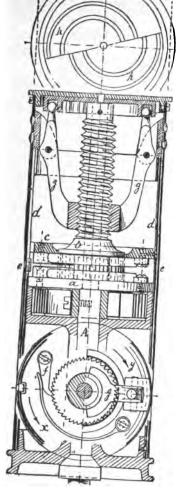


FIG. 30,

drum, a free screw b which is solidly attached to a ratchet wheel. Upon this wheel the two ratchets f are brought in contact. One is fixed immovably to the cover a of the drum, the other is fixed to the ring c which is rigidly attached to the interior cylinder dd, which in turn forms a portion of the pulley. This cylinder carries its alternating movements into the exterior drum ee by means of a ratchet which engages in the luge. The cylinder e has t vo levers gg, which may at will be made to mesh in with the screw b. and on the other side by a ball and socket joint that is attached to the eccentric grooves in the cover hh. The cover is held in position by two small screws, the ends of which penetrate into a circular groove and can be turned by hand, in order to bring the ball and socket joints nearer the center and open the nut, and the drum acts the same as an ordinary indicator drum; but if the nut is brought to mesh in with the screw, the drum ee is raised at each oscillation. Suppose then the movement has taken place in the direction shown by the arrow x: the upper ratchet f will cause the screw to turn with the drum, but upon return, shown by the arrow u, the screw b



FIG. 31.

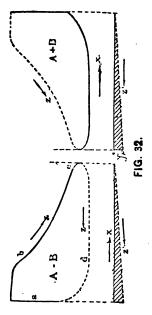
will be held by the upper ratchet and the nut gg turning alone will cause the drum to be raised.

The total elevation is about 1½ in. The number of diagrams of course depends on the pitch of the thread, but care must be taken in order to avoid confusion. A fixed pencil traces the atmospheric line, and finally the diagram may be corrected as above.

ROSENKRANZ VERTICAL MOVEMENT OF THE DRUM.

The fixed axis of the drum (Fig. 31) is threaded at its upper end S to receive a long steel nut M. The exterior of the latter is grooved with longitudinal teeth. A pawl A, attached to the fixed cover of the barrel, catches in these teeth, and a second pawl G opposite to A is attached to the cover of the movable cylinder P. We will now suppose that the drum T' turns in such a manner that the pawl G recedes. The screw M will be held fixed by A, and the cylinder P will turn with T, but on the return, the pawl G will engage with the teeth of the screw M and will cause it to turn in that direction which will be permitted by the pawl A. This nut will then rise upon the screw S, drawing with it the cylinder P, and this will occur at each revolution.

We will then obtain, as with the preced-



ing system, diagrams which are superposed one over the other, and in the solution of which it will be necessary that some corrections be made, of which we will speak later. To take the diagrams we first take off the cylinder P and run the nut M down by hand. Then we put the cylinder P back in place, having furnished it with a new paper. In order to take ordinary diagrams it will be sufficient to suppress the rising movement of P and to do this we draw back the pawl G by means of the button R, so that it cannot engage with the teeth upon the nut M.

CORRECTION OF THE DIAGRAMS.

We will now suppose, first, that the upper curve a b c (Fig. 32) is traced during the first movement of the cylinder P or ee in the direction x when it is not rising. The atmospheric line will then be horizontal. On the return stroke in the direction z the pencil will trace the lower curve c da, but since at this time the cylinder is raising the paper the pencil will trace an atmospheric line upon the return stroke, the line z'. The base y of the triangle of the elevation of the cylinder depends upon the pitch of the screw and the length of th? diagram. It is evident then that it will be necessary to deduct from the surface A of the diagram abcd the surface B of the triangle xyz'. The exact surface will then be A-B. If, on the contrary, it is the upper line which is traced during the return movement z, corresponding to the elevation of the cylinder y, the exact surface will be A+B.

TOTALIZERS—THE ASHTON & STOREY IN-DICATOR.

Each end of the cylinder A (Fig. 44) is put communication with one end of the engine cylinder by means of the cocks d and e, and are provided with the drain pipes f and g. The piston P is attached to the friction wheel q and to the long pinion k, and moves in proportion to the difference of pressure which is exerted upon its two faces.

This effective pressure is kept in equilibrium by the spring h, whose flexibility is proportioned to the pressure. It is, therefore, necessary to have a number of springs the same as in the ordinary indicator. On the other hand the alternative movement of the engine piston is transmitted in a constant ratio to the wheel or pulley a and to a disk b, so that when the pressures upon P are in equilibrium the work is at zero, the friction wheel q stands at the center of the disk b and receives no movement whatever, but when the equilibrium is broken

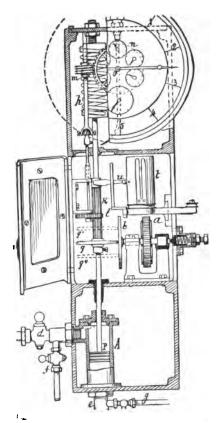


FIG. 46.

the friction wheel q is displaced to the points indicated by the dotted lines q' and q'', and turns proportionately to its distance from the center of the disk b, that is to say, to the proportion of effective pressure.

The number of turns which q makes proportional to the engine is registered by the wheels l and m, and read upon the dials. Suppose the wheel a and the disk b have the same diameter and that their circumference is equal to the stroke of the engine piston. We will suppose also that an effective pressure of 10 lbs. to the square inch causes the friction wheel q to rise to q', which will be the radius of the disk b, then for one foot of stroke of the engine the wheel will develop 10 foot pounds. If now by the clock movement the pointer describes one-twenty-fifth of the circumference of the disk of the friction wheel q, it will develop $10 \div 25 = 2.5$ of a foot pound, which will represent the work of the engine when there is a pressure of 10 lbs. to the square inch upon the piston.

In this apparatus each division of the dial represents say 77.2 foot pounds for an entire revolution of the pointer per square inch of area of the piston. If then, n is the figure which is read upon the dial be-

fore the test, with n' read upon the dial after the test. D the diameter of the engine piston in inches, m the number of minutes that the test lasted, then we will have

77.2
$$(n-n')$$
 $(D^3 \times 3.1416)$

The indicated horse power per second will be

$$FP = \frac{77.2 \ (n-n') \ (D^3 \times 3.1416)}{4 \times 60 \times m}.$$

For a day of ten hours, or m = 600,

$$F P = \frac{77.2 (n-n') (D^{2} \times 3.1416)}{2,400} = K(n-n)$$

 D^2 if we make ----=K for a given engine. 9.895

These formulas are varied according as the circumference of a is equal to the stroke of the engine piston. When the contrary is the case, that is, if c is the stroke of a, and C the stroke of the engine

piston, the constant becomes K---. It will

be preferable, for exactness in these calculations, that the rod of the piston P shall extend out on each side. For two cylinder machines, Woolf or compound, two instruments are employed, or rather we dispose

the piping so that a single indicator can be put in communication with a small or large cylinder at will. It is also possible, in the case of constant work, to measure first the work of each cylinder and deduce therefrom the ratio of the work which is performed by the two. For instance, let α equal the work of a small cylinder and b

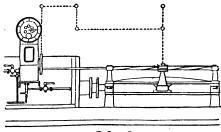


FIG. 45.

that of a large cylinder, then a + b = the total work. For another period in which the work of the small cylinder may be a', the total work x will be

$$x = \frac{a+b}{a} \times a'.$$

In Fig. 45 the instrument is worked by a square bar twisted into a spiral shape, or by levers indicated by the dotted lines.

Fig. 47 illustrates how the wheel or or pulley a is controlled, first by a cord, second by a rack r, and third by an intermediate gearing a', a friction wheel a'' and a rail c, working by friction and held against a'' by means of the tightener a.

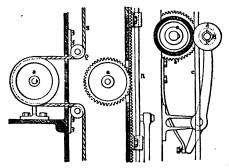


FIG. 47.

This indicator can be adapted with a paper drum t and a pencil u to take off the ordinary or differential diagrams as may be desired.

MOUNTING OF INDICATORS—GENERAL ARRANGEMENTS.

The indicator should be placed in that position which is most convenient for its manipulation, as nearly vertical as possible,

either at the extremity of the cylinder or upon the heads, directly on the cylinder itself preferably, where bosses are provided for this purpose. It should be placed upon straight pipes or those having an easy curve, with or without cocks. When a cock is provided in the piping it allows the indicator to be taken off without stopping the engine. Various types of these cocks are shown in Fig. 59.

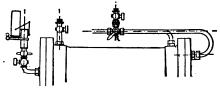


FIG. 58.

With the end A threaded internally to receive the indicator stem, or with the end B threaded externally to receive the nut, it is preferable to put the indicator directly upon the cylinder, especially in high speed engines. Where small piping is employed it is necessary to avoid sharp corners and to give those passages the greatest possible diameter, never making them less than ½ in. or § in.

Fig. 58 shows the method of mounting

with the three-way cock R, in order to take the diagrams successively from each end of the cylinder.

Fig. 59 shows another construction of the cock R, to which the elbow C can be attached for use on vertical engines, and for which the passage a will form the drip. M is the connection that is to be screwed into the cylinder. It receives a nut similar to that of D, which is attached to the cock R.

It is important to make certain that when the engine piston reaches the end of its stroke it does not cover up the orifice of the pipe. We should also avoid putting the indicator upon the steam ports, because, owing to the velocity with which the steam passes through them, a vacuum is obtained beneath the instrument, causing depression which will make a false diagram. The joints should be packed with a cotton thread, without using cement of any kind, because, if the least particle of this is taken into the passages or into the indicator, the diagrams will be changed.

The transmission of the movement of the engine piston to the paper drum varies in the case of each individual engine. One of the most simple consists of an arrange-

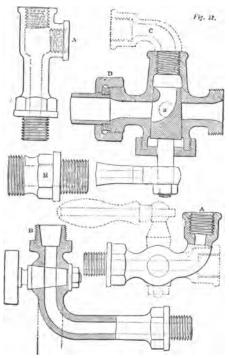
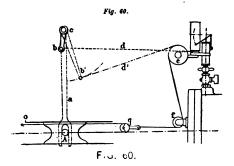


FIG 59.

ment of two levers a, b, in Fig. 60, in the desired ratio of the stroke to the throw of the paper drum; these are put upon the same cylinder by a pin of any design. The lever a is connected to the cross-head by means of a forked lever or small pin. The lever b or b' should be so placed that in its central position it is perpendicular to the



direction of the cord d or d. It is especially essential that its plane of oscillation should be tangent to its paper drum, and the abscisse of the diagram should remain proportional to the stroke of the piston. If the cross-head is not accessible, as in inside connected locomotives, we put upon the end of the shaft and in the plane of the

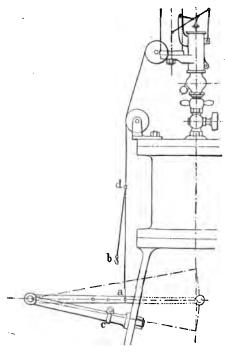
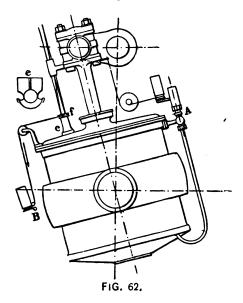


FIG 61.

crank pin an eccentric pin from which the movement may be obtained.

Fig. 62.



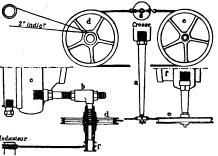
The arrangement shown in Fig. 61 was applied by M. de Maupeou, and permits the paper drum to be stopped even in the

middle of the stroke. The cord is fixed to the lever a at a point which has been determined by the desired reduction of the engine stroke. In order to stop the movement of the drum it is sufficient to hook the end b into the clip c, as shown on the standard. We thus compress the spring of the drum, which remains fixed.

In oscillating engines the movement is taken from the head of the piston, Fig. 62. It is taken to the drum either by means of a cord and reducing pulleys or by means of a rod sliding upon a bar that has been cut with spiral grooves so that it turns at each upward and downward stroke. The standard e carries the spiral bar and the pulley f. This pulley is so arranged that it makes half a turn with each stroke of the piston, and winds up the cord of the drum, which is thus shorter than that used in the preceding.

Figs. 63 and 64 represent a means of transmission that was recommended by the Augsburg society. Upon the cross-head a stem a is screwed, at the extremity of which two ends of a cord, which is wound about the pulleys d and e, are attached. Upon the shaft of the pulley d there are two small grooves cut, forming the pulleys

f, upon which the indicator cords are moved, one being placed at the front end and the other at the back end of the cylinder. This pulley is threaded upon its shaft, which also carries another pulley and thread b, held in position by means of two screws, upon a stem which is screwed and fixed to the engine. These screws



FIGS. 63 AND 64.

permit the desired tension to be given to the cord. At each stroke the pulley d is displaced parallel to its axis an amount equal to the pitch of the thread. This pitch is at least equal to the thickness of the cord, which is thus rolled upon f without the layers being superimposed one over the other.

REDUCING PULLEYS.

Appliances for reducing the stroke are absolutely necessary in the use of the in-

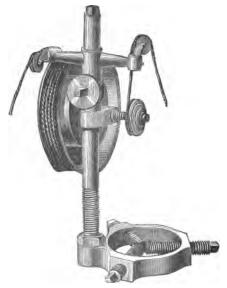


FIG. 65.

dicator. One of the best arrangements is the Stanek pulley, shown in Figs 65. It consists of two pulleys mounted upon the same arbor that is threaded in a movable socket attached to an upright stem. This stem, which may be straight or bent, is threaded at one end and is attached to a ring which is furnished with three set screws, which permit it to be adjusted to any fixture upon the machine.

Two guide pulleys receive the cords. At each turn the pulleys are displaced in a parallel line along their axis a distance equal to the pitch of the thread or to the thickness of the cord in such a way as to prevent the latter from running over itself. A spring is placed inside of the larger pulley, when the cord is unrolled, to bring it back on the return. The small pulley which receives the cord from the drum of the indicator constitutes in its ratio to the large pulley the necessary reduction, and consequently reduces the throw of the engine.

Fig. 66 represents another construcstruction. At each turn of the threaded axle the lever which comes around the side of the wheel and catches the cord is drawn aside, one end guiding the cord which comes from the cross head and the other that which leads to the indicator drum. The upright is sorewed into some fixture

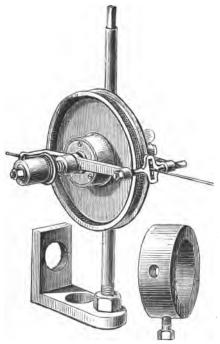


FIG. 66.

upon the machine either into a square stop or into a ring, which may be attached to any convenient part of the engine. This apparatus can be attached directly to the indicator where there is a pin of some kind on the machine. The screw which produces the displacement of the pulleys at each turn is on the inside and attached to the support.

The pitch of the thread renders the socket fixed, hence it is only adjusted in connection with the necessities of the case.

In all these cases it is easy to calculate the diameter of the small pulley in order to obtain the necessary reduction. Let C be the stroke of the engine in inches, D the diameter of the large pulley whereon the cord is rolled, c the length of the diagram, and d the diameter of the small pulley where the cord is rolled. With paper drums of from 2 to $2\frac{1}{4}$ in. in diameter, the length of the diagram will vary from 3 to 4 in. The diameter of D and d should be reckoned from the center of the cord, the diameter of which will be somewhat less than $\frac{1}{4}$ in.

We shall then have
$$\frac{C}{c} = \frac{D}{d}$$
, or $d = \frac{Dc}{C}$

The number of turns of the pulleys will

be
$$N = \frac{C}{3.1416 / l}$$
.

Then, if $D=4\frac{1}{16}$ and c=4, we shall

have
$$d = \frac{16.25}{C}$$
, $n = \frac{C}{12.7628}$

We have thus calculated the diameter of d when the cord is rolled, and consequently the diameter of the reels of the small pulleys in employing a cord which is about $\frac{1}{16}$ " thick.

Stroke of piston C in inches	60	48	86	27	18
Diam. of pitch of d pulley	.271 .208	.83 .276	.451 .389	.602 539	.903 .840
Number of pulleys	1	2	8	4	5

These five pulleys will avail for all intermediate strokes if the operator is willing to content himself with diagrams which are shorter than 4". The length may be

$$c = \frac{C \ d}{D}$$
. In taking $D = 4\frac{1}{16}$, and the

diameter of d corresponding to the five numbers above, we shall obtain for these

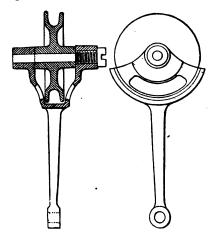
strokes the following table, c being the corresponding length of the diagram:—

N	о.	1				2			
	c.	60	56		52	4	44	40	
	c	4	8.78	3	466	4	3 658	3.326	
3 4			4	-	5				
36	33	3)	27	24	21	1	12	6	
4	3.660	8.83	4	3.552	8.11	4	2.66	1.88	

We end this description by offering a reducing apparatus having two different arrangements, which can be employed in case very long strokes are to be indicated, and for which the apparatus just described will not suffice.

We will suppose the reducing pulleys shown in Fig. 60 are mounted upon the same indicator. We then employ, in addition to these pulleys, the levers a and b', or an idle pulley f, and a movable pulley g, which takes the cord in place of

the groove at the end of the lever, and is attached at the other end to the fixed point O. Figs. 67 and 68 represents such a pulley as made by Schaeffer & Budenberg.



FIGS 67 AND 68.

FUNCTIONS.

The functions of the indicator will be placed under two heads, those which operate the pencil, and those which drive the paper.

PISTON.

The operator should be certain that the piston does not experience any sensible friction as it is being moved by hand, or, by becoming unscrewed, strike the cover. A piston which is too free may occasion some defects which are of little importance in non-condensing engines, but in condensing engines it will allow the entrance of air which will alter the effect of the pressure on the indicator piston. This effect is exceedingly sensitive if the steam pipe under this piston is long and straight.

SPRING.

This is the most important part of the indicator. Care should be taken, in placing the spring, that it is firmly screwed up at both ends. The scale of deflection should be verified before and after each test, operating it both cold and hot. When it is operated cold, we place the indicator in a vise, then load the piston vertically with successively increasing weights. We measure the flexure corresponding to each load, and draw a line with a pencil upon the paper by hand. We repeat these observations, gradually unloading the piston. Let q equal the load in pounds producing a deflection of $\frac{1}{63}$ in. and s be the section

of the piston. $\frac{q}{s} = p$, the pressure per sq. in. for 1-32 in. flexion. Let e be the scale of flexion of the spring for p = 1 lb.

Then $e = \frac{1}{r} = \frac{s}{r}$

This operation can be carried on by successively loading the piston with weights corresponding to 1, 2, 3 lbs. per square inch of section, and measuring the flexion as above indicated. We have thus the proportion of the flexure to the con-

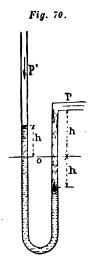
stant load. $\frac{f}{1} = \frac{f'}{2} = \frac{f''}{3} = e = \text{the scale}$ of the spring.

If it appears preferable to test it while it is hot, it should be heated to about 212° F., for, the spring being longer when hot than when cold, we will have in this last case an increase of from 2 to 3 per cent in the results. In order to work for the verification of a hot spring, we place the indicator under a receiver, communicating by means of a cock with a boiler and with a manometer that is free from air. We then admit the steam gradually into the reservoir, and at each increase of pressure

from one pound or from one atmosphere, we make as before a pencil mark which will indicate the degree of flexure. When we have obtained the maximum pressure we close the cock, then the steam gradually condenses and the lower pressures will be indicated. We verify this by seeing that the pencil traces for each pressure the same lines that it did in ascending.

By continuing this decrease of pressure down to below the atmosphere, we can determine the scale of the spring for its extension. This scale will differ a little from that which was found for compression. We will in each observation detect a slight vibration of the spring, without which the differences between the ascent and descent would be very much exaggerated. These differences can be accounted for by the spring alone or by the play of the articulations and the bending of the moving pieces composing the indicator. Should there be any extensive friction of the pencil, the pressures can be measured by a mercury column connected with a manometer that is free from air, and in taking account of the water which by condensation is collected in the smaller arm of the column. In Fig. 70, h' represents the constant dis

tance in inches from the steam pipe to the average level of the mercury in the two columns,



h = the lowering of the mercury in the short branch, in inches;

P = the absolute pressure of the steam expressed in atmospheres;

H =the height of the barometer in inches:

$$p' =$$
the atmospheric pressure $= \frac{H}{30}$

This 30 is taken as the height of the mercury in the barometer in inches in its

normal position, and the fraction - = that

fraction of the normal atmospheric pressure existing at the time of the experiment.

We will then have for the value of P in atmospheres:

$$P + \frac{h+h'}{407.337} = \frac{2h}{30} + p'.$$

Whence
$$P = \frac{26.1558 \ h - h'}{407.337} + p' \qquad (a.)$$
The 407 327 — the height of a herometric state of the state of the

The 407.337 = the height of a barometric column of water in inches when the mercury stands at 30 inches.

Formula (a) expresses P in atmospheres. To find P in pounds per square inch we multiply the value given in (a) by 14.7. Then, performing the divisions so as to express the fractions decimally, we find

$$P =. 9439 h -. 039 h' + 14.7 p' (b);$$
and
$$h = \frac{P + .039 h' - 14.7 p'}{.9439} (c);$$

h' being a constant number, formula (c) permits us to graduate the manometer for the atmospheric pressure of the place.

For example, let h' = 30 in.; h = 40 in.; p' = 1 atmosphere.

(a) gives
$$P = \frac{1046.232 - 30}{407.337} + 1 = 3.494$$

atmospheres.

(b)
$$P = 37.756 - 1.17 + 14.7 = 51.36$$
 lbs. per sq. in.

(c) gives for

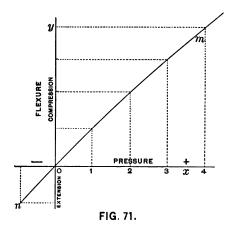
P -	80	40	50	60	70	80
h -	80 17.45"	28.04''	38.61"	49.23	59.82"	70.42

It is also possible to secure the graduation of the springs by means of hydraulic pressures. This is the only means of testing the springs of the Rae and Kenyon indicators when cold.

In this case, when working with steam, especially if acting under high pressures, it is preferable to employ a well made safety valve to a manometer, say with a diameter of from 1½ in. to 2 in., with a contact of 3 in., and to take for the effective surface that corresponding to the mean diameter of contact.

RATIO BETWEEN FLEXURE AND PRESSURE.

In order to draw a line showing the relation existing between the pressure and the corresponding flexures of the spring, we lay off as in Fig. 71, and starting from the origin o of the co-ordinates upon o x



the positive pressures to the right and the negative pressures to the left; then upon oy the deflections corresponding to these pressures, the positive above and the negative below ox. By drawing the co-ordi-

nates, we finally obtain the lines of relation o m and o n.

In ordinary indicators, the deflections are in direct proportion to the pressure; hence o m is a straightline. This ratio especially facilitates the calculation of the average co-ordinate, by permitting the use of the planimeter.

PARALLELOGRAM.

The parallelogram of the indicator includes all of the joints. It is necessary to be certain that they are all free, but without play.

The straightness of the line drawn by the pencil can be tested by causing the piston to act while the paper remains stationary.

To make sure that there is no undue friction, we should first move the piston by compressing the spring, and then allow it to come back into position and at the same time draw a line upon the paper. We then move it in the opposite direction by elongating the spring, and it should come back to the same point and draw a line which exactly coincides with the first one.

THE PENCIL.

A hard pencil should be employed. It has been found best to use, however, very

frequently, a metallic stem with a fine point rounded off on the end so as not to tear the paper, and which draws a faint line upon paper prepared with oxide of zina.

The pencil should run over the paper It should be as light as without friction. the socket that holds it, for its weight acting at the end of the lever, where the

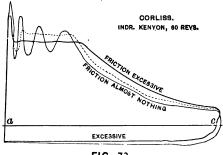


FIG. 72.

velocity of motion is at its maximum, will tend to increase the oscillations. The friction of the pencil tends to lessen the oscillations, but at the same time it falsifies the diagram. The diagram, Fig. 72, shows this effect very well. We see that, during admission, the line of the diagram is too high or too low, according as the pencil comes to a standstill at the end of its upward or downward motion. This friction raises the line of admission as well as that of the exhaust.

FRICTION OF PARTS.

When friction exists in the articulations, especially of those by which the piston is joined to the pencil, the curve presents sharp corners, due to the jerked movement of the pencil, in consequence of the difference existing between the coefficients of friction at the beginning of and during its movement.

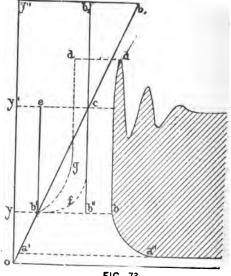
OSCILLATIONS OF THE PENCIL.

These oscillations are due, as we have said, to the momentum acquired by the parts that are put in motion under the sudden action of the steam and the reaction of the spring. Subjected to these two forces, the piston oscillates about its position of equilibrium, and the pencil traces undulating lines.

A graphic representation of this action is clearly set forth in Fig. 73.

Let us suppose that the pencil exactly follows the motion of the piston, as in the primitive indicators. We will take the

pencil at a", the point where the exhaust closes. During the compression a''b, the flexure is practically in a direct ratio to



FIG, 73.

the pressure, and the line of proportion a'b' is obtained. At b the admission suddenly takes place, and the piston receives the pressure b' b" without variation during its rise bc; on reaching c, the work performed upon the piston is b'b''cc. Meanwhile the spring opposes a resistance increasing in proportion to its tension, which, being yb' in the beginning at b, has become y'c and has absorbed an amount of work represented by the triangle b'cc.

The excess of work accumulated upon the piston, represented by b' b'' e, tends to continue the compression of the spring until it shall have been absorbed; that is to say, until c b_1 b_2 = b' b'' c. The pencil should therefore rise along c b_1 , then the reaction of the spring should drive it down again to b''.

But, in reality, the piston never rises to b_1 , because the action of the steam at b is not instantaneous as laid down in the line b'b'', but acts along the curved line f. Furthermore, the friction, shock, etc., reduce the pressure, and finally, the surface of the work is limited by b'gd; then this constant friction reduces each successive oscillation.

During the period of admission the equilibrium is better established. Nevertheless, on engines using high pressure, a considerable oscillation is frequently pro-

duced at the point of cut-off. This oscillation may also be due to a friction of the pencil, which, by retaining it, causes a sudden reaction of the spring.

During the exhaust the oscillations are smaller, because the pressure upon the piston is less.

In analyzing the law regulating the vibratory movement of the piston, M. de Maupeou has established this formula for the duration of an oscillation:—

$$T = n \frac{\sqrt{me}}{se}$$
 (a)

T =time of oscillation.

m =mass of the moving parts.

e =scale of the spring.

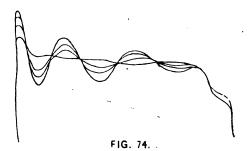
s = section of the piston.

This formula shows that the time of the oscillations is independent of the amplitude. Fig. 74, in which there are oscillations of varying amplitude, verifies this conclusion.

It is advantageous then to reduce m and e, and to increase s in order to diminish T, for, the more rapid the oscillations, the more quickly they will disappear, for the same number, and the less will be the risk of deforming the diagram by them at the

beginning of or during the expansion. M. de Maupeou has reached the conclusion, from this point of view, that the rapidity of the oscillations ought to be proportioned to the speed of the engines, and increase also as the time for admission is shortened.

It is in this respect that the indicators as



now constructed, with a short stroke for the piston, copied from the Richards design, have advantageously replaced the old types for use upon modern engines.

In the Garnier-Martin indicator an attempt was made to reduce the sudden action of the steam under t'e piston by the introduction of a valve, but it does not seem to have been a success.

If we notice that compression diminishes the sudden action of the steam under the piston, we can naturally conclude that, in order to diminish the oscillations, it is advisable to employ springs as stiff as possible, in proportion as the compression decresses.

MOVEMENT OF THE PAPER DRUM.

The drum should be perfectly round, and the paper well stretched upon its surface. Its movement is given it by hemp, gut or metallic cords, all of which are more or less elastic.

The result of this elasticity is that, at the end of the stroke, the cord, having to overcome the inertia of the drum, the reducing pulleys and the tension of the springs, stretches more or less; the drum loses a part of the stroke; then the cord, gradually regaining its original length, ends by giving the drum a motion proportioned to that of the engine piston.

We therefore have a curtailment of the diagram and a reduction of its surface, which increases with the speed of the engine and the elasticity of the cord.

But an elongation of the diagram is often produced on high speed engines by the throwing of the drum, as shown in the

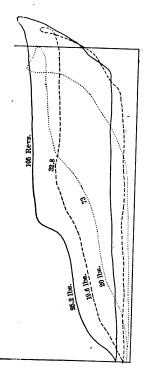


FIG. 7

diagrams, Fig. 75. This throwing diminishes with the weight of the drum and the other moving parts. For a given indicator this elongation is lessened by reducing the throw of the drum and by increasing the tension of the recoil spring in proportion to the more or less rapid motion of the engine.

In the Garnier Martin indicator, the control of the drum by means of a helicoidal clutch annuls the effects of inertia.

THE CORD.

The cord should be flexible and inelastic. It is most frequently made of hemp or



FIG. 76.

gut, but metallic wires and steel bands are also used. A hemp cord should be stretched before it is used, and it should be dry, for dampness will increase its elasticity; it should run as straight and be as short as possible; and it should have a regular linear movement, without shaking or oscillation.

The length can be adjusted when the

engine is at rest. In order, however, to adjust it while the engine is in motion, it is convenient to use a small plate, shown in Fig. 76, which is punched with three or four holes, and which can be slid along the cord.

In indicators that are in bad condition it

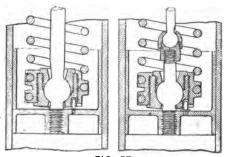


FIG. 77.

may happen that, when compressed, the spring bends sideways, producing an oblique thrust and consequently an abnormal friction upon the piston and the piston rod. To obviate this tendency it has been proposed to connect the spring to the piston rod by means of a ball and socket joint as shown in Fig. 77. But, as this in-

volves a greater complication, the suggestion has not been carried into effect.

END OF VOLUME ONE.

Fuels, Evaporation and Combustion.

5-25.52

Translated and Reduced to American Standards

BY

GEORGE L. FOWLER, EDITOR "POWER,"

FROM THE FRENCH OF J. BUCHETTI.

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PREFACE.

This little book is offered to those who are interested in the care or ownership of steam boilers, and to whom the question of the consumption of fuel is of vital importance. Too little is known by the men in charge of the steam plant regarding the constituent elements of the fuels that they are using, and the meaning of the dense volumes of smoke that issue from almost every chimney in the country. Smoke is nothing but smoke to very many and seems to be considered an indispensable accompaniment to the burning of fuels of every kind.

An attempt has been made to simplify the grades into which ordinary fuel has been divided and to show how it can best be employed in the production of steam. There is also added a description of a means of testing the products of combustion and thus learning whether the best results have been obtained. While the book is only one of a series that will be issued on the general subject of the testing of the steam engine and the means employed to determine its efficiency, it will be found to be complete in itself, and to contain, it is believed, much data that is new and valuable to the man in charge of the steam plant.

G. L. F.

New York, Dec. 6, 1886.

FUELS, EVAPORATION AND COMBUSTION.

I. FUELS.—CALORIFIC POWER.

The sun, which is the source of all vegetation, has at some time had shut up within itself all that heat which is now made available in the several fuels.

All those bodies are called fuels which are capable of combining with the oxygen of the air. Such a combination is combustion, and restores the heat and light that had originally been taken from the sun.

Commercial fuels are supposed to contain when dry: 1. A certain amount of oxygen and hydrogen combined in the proportion of eight to one, forming the constituents of water and furnishing no heat. 2. A certain amount of inert substances which also give out no heat, as azote, the mineral matters composing the cinders, and frequently iron pyrites or sulphate of iron, which may be disregarded because of the feeble calorific power of sulphur. 3. Finally, free carbon and hydrogen, which are the elements of combustion in the production of heat. We will now review this combustion.

(5)

In judging of the quality of a fuel, we must look to its resulting heating power, its density, its cohesion, its behavior upon the grate, the readiness with which it burns, and, finally, the nature of the resultant cinders.

Those which are argiloferous or of a clayey nature, containing iron, produce by their fusion a kind of iron dross which clogs and burns the grates, while those which are of an earthy nature fall through without obstructing the passage of the air. The calorific or heating power (P) of a fuel is then the number of calorics or heat units which a pound will disengage in the course of its combustion. According to Dulong it is equal to the sum of the calorific powers of its elements, namely, free carbon and hydrogen.

According to Fabre and Silberman the calorific power of carbon, which is represented by C, is 14,580; that of hydrogen, H, is 62,150. (By this the reader should bear in mind that this calorific power represents the number of heat units in one pound of carbon or hydrogen. A heat unit is the amount of heat required to elevate the temperature of one pound of distilled water one degree Fahr. from 39° to 40°.

The water is taken at this point because it has there its greatest density. So that for the case in hand we learn that one pound of carbon, when completely consumed, would raise 14,580 pounds of water one degree Fahr.—Trans.) In analyses of fuels oxygen is frequently confounded with azote. the latter being of little importance. Oxygen (O) being combined with hydrogen (H) in the proportion of eight to one to form water, the proportion of the free lydrogen in the fuel would be $H = (0 \div 8)$, or the total weight of the hydrogen in the fuel less one-eighth the weight of the oxygen, this one-eighth being united with the oxygen.

Dulong's formula for the pure fuel is $P = C \times 14,850 + (H - (O \div 8) \text{ or } 62,150$

(The meaning of this is that C, H and O represent the percentage of carbon, hydrogen and oxygen in the fuel. An example will be given later.—Trans.)

This law is not exactly correct for fuels possessing a high percentage of hydrogen, but such should be tested by means of a calorimeter. If a is put equal to the percentage of water, and b to that of cinders, the true calorific power may be expressed as: P' = P(1-a-b). That is, supposing

that: 1. The steam formed during combustion is condensed and then cooled to 32° Fahr., so that it gives up all the heat absorbed in its evaporation. 2. That all the other residues are also cooled to 32° . But it must not be understood that this state of affairs obtains with boilers; the steam passes out into the chimney and carries with it 1146.6 units of heat for each pound of steam when the temperature is considered to be 212° Fahr., to which must be added the heat corresponding to the excess of 212° existing in the temperature t of the gases in the chimney or (t-212.)

(For example, suppose a pound of steam is carried off among the gases having a temperature of 240°, then 1146.6 units are lost for the first 212° and $.3 \times (240 - 212) = 3 \times 28 = 8.4$ units additional or 1146.6 + 8.4 = 1155 in all, the .3 being a fixed coefficient.—Trans.)

If h is the weight of hydrogen contained in one pound of fuel, its combustion yields 9 h of water for 8 h (of oxygen) is united to h, and the total amount of water evaporated is a plus 9 h, or the original water contained in the fuel and that formed by he combustion of the hydrogen.

It becomes necessary, then, to deduct

from the true calorific power (P') of the fuel the heat which remains in the cinders and ashes; but this loss as well as that due to the temperature (t) of the escaping gases, is among the other causes of loss in the fire-boxes, and can be determined, as we shall see, by multiplying the absolute calorific power by a coefficient upon the basis of a reduction to a temperature of 32° of the condensed water. We take then:

The true calorific power P' = theoretical calorific power P (1-a-b)-1146.6 (a plus 9 h.)

Commercial fuels may be divided into five classes:

Wood, charcoal, barks.

Peat, peat charcoal.

Lignite.

Bituminous coal, coke.

Anthracite coal.

To these solid fuels we may add: Gas, oil, tar, petroleum.

WOOD.

Woods may be distinguished as hard and soft, or green and dry.

According to Brisson, the average specific gravities of different woods may be written as follows:

Heart of dry oak	1.17
Beech and ash84	to .85
Alder " apple79	" .80
Maple "cherry	.75
Elm " walnut	.67
Pear	.66
Willow	.58
Fir (male)	.55
" (female)	.49
Poplar	.38
Cork	.24

Wood always contains more or less of water, and can only be used after having been partially dried either in the air or in a dry house at a high temperature. Wood should be cut during the winter. It then contains from 40 to 45 per cent. of water; after 6 months it will have 26 per cent.; after a year 20 per cent., and after 18 months about 17 per cent.; after which time wood that is merely exposed to the air will lose no more water; but when wood has been previously dried and is afterwards exposed to the air it will gradually re-absorb from 14 to 16 per cent. of water.

Wood that has been dried at a temperature of 285°, contains 50 per cent. carbon; 1 per cent. free hydrogen; 46 per cent. of

oxygen and hydrogen in the proportions necessary to form water; 1 per cent. azote and 2 per cent. cinders.

According to the law of Dulong we have: $P = .5 \times 14,580 \times .01 + 62,150 = 7,911.5$.

This remodeled according to our directions gives P'=7,911.5-1,009. (.46 \pm .09) = 7,356.5 caloric units. (This 1,009 = 1,146.6 \times .88. The .88 being 100 less the percentage of ashes and hyrogen. 1,146.6 is the number of calorics required to evaporate one pound of water from 32° Fahr. – Trans.)

The following table contains the weight and calorific power of one cubic foot of wood heated to 285°, according to Chevandier.

That of one pound of wood varies from 7,660 units of heat to 7,920; average about 7,911, as given above.

Hard wood burns upon the surface, furnishing abundant carbon, while soft wood cracks open under the influence of the fire and burns rapidly down to the center, sending forth flames until the end of the combustion.

The more wood is cut up the more rapid is the combustion, and the greater the useful effect, because the air is more effectually utilized; but this cutting up is a source of expense.

		Carbo Wt.in per c.		Fre	Heat Units		
	KIND OF WOOD.	in lbs	arbon	gen.	per cub.ft.	rela tive	
From trunks.	Oak from old tru ks Beech Elm—(yoke) Oak—(small trunks). Birch Alder Fir Pine	23.65 23.03 22.28 21.05 18.24	11.46 11.13 11.08 10.71 9.26 8.78	.1643 .1855 .1538 .2273 .1855	191,450 190,313 181,680 180,863 179,806 155,590 145,961 135,236	0,994 0,95 0,945 0,939 0,812 0,762	
Fr. branches.	Beech. Fir. Pine. Elm—(yoke). Birch. Oak—(both kinds).	18.92 17.86 17.49 18.55 17.74 17.25	8.09 8.89 8.95 8.47	.1626 .1146 .1806	3 152,246 150,016 5 148,425 5 146,240 5 143,979 4 139,583	0.79 0.779 0.764 0.749	

Wood charcoal is obtained by carbonization in furnaces in the forests. Calcination begins at 302° Fahr., and the product varies with the temperature. When subjected to

From 302° to 518°, the production = 30 to 37 per cent. in the form of firebrands.

From 536° to 626° production = 32 to 36 per cent. as brown coal.

From 644° to 752°, production = 18 to 31 per cent. as black coal.

From 752° to 2,750, production = 17 to 18 per cent. as hard and black coal.

The production in weight, which is really

the only thing that should be considered, varies from 18 to 20 per cent. of the original weight.

The weight per cubic foot varies according to the nature of the case.

ing to the nature of the ca	se.		
	At th	e cei	ater.
For oak and beech			
" birch	l3. 7'	· 14.	39 "
" pine	l1.45'	· 13.	07 ''
According to Ebelmen	the ave	raĝe	com-
position of charcoal that h	as beer	ı dep	rived
of water is:			
Carbon		. 875	parts
Hydrogen		.030	- "
Oxygen and agate		.075	66
Ashes			"
	-		

The free hydrogen amounts to about 2 per cent., and the heat units are $P = .875 \times 14,580 \times .02 \times 62,150 = 14,000.5$, which, for a pure fuel, would be:

1000

$$\frac{14,000.5}{.98} = 14,286.22$$

For a charcoal containing .06 of water and .04 of ashes, we should have .09 of carbon anp the formula would become:

 $P' = 14,286.21 \times .9 - 1,009 (.06 + .9)$.02 = 12,888.95.

The relative values of the different char-

coals are in proportion to the weights of the same volumes or their specific gravities.

Bark, Tanbark and Sawdust.—These fuels are very finely divided and generally damp. Theoretically they have the same heating capacity as the wood from which they are obtained. Tanbark, after its passage from the press to the cylinder, contains about 4.8 per cent of water, 8 to 12 per cent of ashes, and weighs 20½ lbs. per cubic foot. Its true heating capacity, deduced from dry wood with 2 per cent of ashes, will be

P' = 7.911.5 $(1 - .48 - .1) - 1.009 \times .48 = 2,838.51.$

Admitting that $\angle 0$ per cent can be utilized, we would have $2,838.51 \times .50 = 1,135.4$, and $1,354 \div 1,009$, the total units of heat absorbed = 1.12 lbs of steam per lb of fuel.

Now a ctual tests have given 0.82 lbs. of steam per lb. of tanbark, and 0.90 lbs. per lb of sawdust.

These fuels burn better if mixed with bituminous coal. Their poor utilization results from a part of the fuel being carried off into the flues.

PEAT.

Peat (mossy, leafy or from embers) re-

sults from actual vegetable decomposition. This is very apparent in the upper layers, while for the lower layers which are denser and blacker, these vegetable formations are no longer distinguishable.

Peats dried in the open air contain, according to the localities, from 20 to 30 per cent. of water, and from 10 to 25 per cent. of ashes. The weight of a cubic foot weighs from 14 lbs. to 19 lbs. The fuel is light, cumbrous and spongy; it burns poorly with a smoke of a strong and disagreeable odor. After grinding and washing it is pressed into briquettes.

Peat is improved by drying up to a temperature of 212°, (or below that which causes its decomposition) but it is necessary to use it where it is dried, if not it will re-absorb the dampness.

The analyses of Regnault and Marsilly show that dry and pure peat contains on an average:

Hydroge	nand azote	06
,8		1.00

The free hydrogen gives $.06 - \frac{.37}{8} = .0137$

The heat units are theoretically P =

 $0.57 \times 14580. + .0137 \times 62150. = 9126.05.$ And the real capacity P' = 9126.05 - 1,009. $(9 \times 0.06) = 8,582.19.$

For a peat containing 8 per cent of ashes and 25 per cent of water the capacity would be, $P'=8,582.19\times.67-1,009\times.25=5497.81$ (.67 = 1.00 — .08 (% of ashes) — 25 (% of water) Trans.)

Peat charcoal is obtained by carbonization of the peat in furnaces, in mason-work pits or kilns, or in sheet iron crucibles.

The product contains from 40 to 45 per cent. of carbon, and from 15 to 20 per cent. of ashes.

The gas resulting from the combustion of this charcoal preserves the strong and disagreeable odors of the peat.

The Essone charcoals with 18 per cent of ashes have a calorific power of $.82 \times 14,580 = 12,155.6$ for the fuel itself when deprived of water.

FOSSILIZED FUELS.—LIGNITES.

These fuels mark a transition state between the peats and the coals. They are sometimes brown with a ligneous texture, or of an earthy appearance, sometimes black with a ligneous texture, orhomogeneous, giving a resinous fracture. These last, jet for instance, are analogous to coal.

Regnault distinguishes imperfect lignites or fossilized wood in the process of transformation into lignite; perfect lignites; and the lignites or bituminous woods in process of transformation into bituminous coals. They are characterized by the proportions of the oxygen to hydrogen, and the fixed carbon or coke which they contain.

The calorific power (P) of the pure fuel has deen directly determined by Messrs. Scheurer-Kestner and Meunier.

Fuel.	Coke per ct.	<u>н</u> о	H	P	P1
Imperfect lignite Perfect " Bituminous "	75 65 to 70 85 to 40	to 6 5 to 2	4	9526 12780 14040	10010

With .08 of water and .10 cinders, for the three varieties we obtain the true caloric value P₁.

For instance for perfect lignite we have $P_1 = 12,780 \times .82 - 1009 (.08 + 9 \times .04) = 12,414$.

COALS.

Their color is black, their appearance schiftous or compact. They comprise a great number of varieties. Regnault and Gruner divide them into five classes.

Coal, dry, producing a long flame.

- " oily, producing a long flame (suitable for making gas.)
 - " oily (blacksmith coal.)
- " oily, producing a short flame (suitable for coking.

Coal, hard or anthracite, or dry, with a short flame.

Dry coals, producing a long flame:—Sandkohle (German), Splint coal (English). These give 60 per cent. of a coke slightly calcined, in pieces that possess little adherence; the flame is long but of short duration. These coals are used upon a grate and under boilers but have lower heating properties than those that follow. A cubic foot weighs 57 lbs. They are rarely found in France; those that most nearly approach them are those of Saint-Eloi and those of the upper beds of Blanzy and Montoeau.

Oily coals with a long flame. Cherry coal (English). These agglutinate in the fire without caking. They are fine coals for the grate and for gas making. The *Flenu* of Mons and the cannel coal of England are the finest samples of this kind of coal They are more abundant in France than those that have been just mentioned and

form the upper beds of the Pas-de-Calais, of the Loire, of Commentry and Blanzy.

Oily blacksmith coals. Coking coal. (English), Backkohle, (German). These have an oily appearance and are of a beau tiful black; they are not very hard and have a structure that is more or less leafy or laminated; in the fire, they yield to a more or less putty-like fusion and produce a light, swoollen coke that is of little use in metallurgical processes. There are a few grades that give a good coke. Upon the grate they cake, intercept the air and burn the bars, but give a great deal of heat. They abound in France in the basin of Saint-Etienne, of the North and of the Pas-de-Calais. A cubic foot weighs from 57 to 65 lbs.

Oily coals producing a short flams.—
These are less liable to cake than those that have just been mentioned, give a good coke and are preferably used in metallurgical processes. In Belgium they are called lasting because they last well in the fire; in reality they are friable. They are found in France at Creuzot, at Saint-Etienne, Brassac, Huy, in Gard and the North.

Delautel made some tests of this kind of coal at Brest.

THE CHICAGO POWER OF THE		
from Cardiff being consider	ed as 1	l, he
found for the		
Oily coal of Anzin	1.05 to	1.01
Coals from Roche-la-Moliere	.95 to	.94
Chalm (andimonal) from the To	_:	00

Coals, (ordinary), from the Loire .90
"from Newcastle .84

" Blanzy (Montceau) .78

(dry) with long flame ".74

Hard or anthracite coals with a short flame.—These are black, striated, offer a dull fracture, have slight cohesive qualities, burn with some difficulty, produce no smoke and often crackle while burning. Their coke is in the form of a powder They are rare in France, and are not burned upon the grate there. A cubic foot weighs 69 lbs.

Average weight of a tew coals:

Average weight of a few con	uus:
Mines of Labarth	56 lbs.
" Auvergne, Blanzy	55 lbs.
" Combelle	54 lbs
" Lataupe	531 lbs.
" Saint-Etienne	53 lbs.
" Decize	52 lbs.
" Mons	80 lbs.
" Creuzot	49 lbs.

The calorific power of coal has been measured by several experimenters. In table A we give the averages: 1st, of the

elementary composition: 2nd, of the yield of coke, which characterizes the five types of coal that are supposed to be pure; 3rd, of the theoretical calorific power (P); and 4th, of the amount of water that can be evaporated at 248° taken at 32° Fahr.

For coal containing 2° of water, 10° of cinders, the proportion of hydrogen will be reduced to .88×.05 and

 $P' = 15,570 \times .88-1,009 (.02+9 \times .044)$ = 13,298.

TABLE A	-Gi	ving	the a	ver	age of	five i	kin	ds of coal.	
	Co	mno	sition	128	pure	trom.	Coke.		
Kinds of Coal		er c		Katio. O	8 28		per c	Nature.	
	C	Н	0	H	: 3	. ₽	:		
Dry, with	75 to	5.5 to	19.5 to	4	14400 to	6.7 to	50 to	Brittle and	
long flame.	80	4.5	15.5	. 3	15300	7.5	60	powdery.	
Oily, with long flame	80 to 85	5.8 to 5	14.2 to 10	_	15300 to 15560	7.6 to 8.3	60 to 6	Heavy and porous.	
Oily, merchant	84 to 89	5 to 5.5	11 to 5.5	-	15840 to 16740	8.4 to 9.2	6 to 74		
Olly, with short flame	88 to 91	5.5 to 4.5	6,5 to 4.5	1	16740 to 17280	9.2 to 10	74 to 82		
Dry or anthracite	90 to 98	4.5 to 4	5.5 to 8	1	15840 to 17400	9 to 9.5	to	Brittle and powdery.	

It is in this way that we have calculated the calorific power (P') of table (C).

We learn the value of a coal by making a direct analysis. After a drying which gives the hydrometric proportion of water, we distill the remainder in a close vessel in order to determine the nature and quantity of the coke; then by burning the residue left from the distillation the proportion of cinders is determined

This drying is carried up to about 230 degrees by putting from 60 or 75 grains of the material in a test tube. The incineration is effected upon about 50 grains of material, confined in porcelain capsules placed in a muffle or oven that has previously been heated to a white heat in order to avoid the formation of coke, which hinders the operation.

Several capsules are operated upon at the same time, an average taken of the result. The incineration occupies two hours with coal and four with coke. The direct evaporative tests made by Messrs. Scheurer-Kestner and Brix, given in resume in the following table, agree with the data of the preceding. In reckoning 1146.6 calf orics per pound of water at 212° Fahr., we have deduced the co-efficient for each type

of coal (K) that may be considered pure. We can then adopt .6 as the average.

TABL	в В.—	Evapo	rative R	esults.		
Kind of Coal.	Percei	ıtage.	Water Evapora- ted from 32° to 212° per lb. coal.			Coefficient
	W'ter	Ash	Merch.	Pure	coal	nt
lst—Dry, with long flame. Gerhardt Mine (Saarbruck) Leopold (Upper Silesia) Louisenthal (Saarbruck) Monteau (Saone and Loire) 2d—Oily, with long flame. Friedrichsthal (Saarbruck) Attenwald 2d—Merchant. Ronchamp Le President	4.10 8.57 4.97 1. 2.54 1.09	6.84 5.1 12.29 10.28 12.7 18.5 16.19	6.2 6.31 6.95 7.62	7.78 6.72 7.29 7.41 7.78 8.27 9.16	172 7.	9090 9172 8370
(Saarbruck)	1.4	2.28	8.11	8.47	8.81	क । ह्र

Coal containing the carburets of hydrogen burns spontaneously when it is in large pieces, especially if it is at all damp or pyritous; and it is necessary in this case to keep the currents of air from the mass. If they are too pyritous in nature, they may be preserved or kept in basins full of water. Coals that are used in making gas change

rapidly in the air; their loss in gas reaches about 30 per cent a month when exposed to the air. In practice the ashes reach a proportion greater than that which is given by chemical analysis; it reaches six to ten per cent for moderate size pieces, and varies from ten to twenty in current practice as coals run, and according to the care which the fireman takes in using them, and their nature. Coals are classified as large, intermediate, and fine coal; as they run it is a mixture of these three classes.

Briquettes.—Fine pieces of oily coal are agglomerated by heat; or small, oily or dry pieces are agglomerated with tar and c ay. The calorific power of this material when thus dried, is deduced from that of the coal of which it is composed, taking it for granted that the matter is pure, and modified, of course, by the amount of water and ashes which it contains.

Coke.—This is the result of the distillation of the coal; it contains from 4 to 15 per cent. of ashes, or more, according as it it made from large or fine pieces, and according to the amount which is contained in the coal from which it is produced. It contains also from 2 to 10 per cent. of water. This fine coal, if it has been previously washed, gives a pure coke, and at a price higher than that which is made from the same grade of coal, but which has not been washed. Table A gives the average nature of coke for different coals. A cubic foot weighs from 43 to 48 lbs., and the gas about 15 lbs. The calorific power of the coke has not yet been exactly determined, but it may be deduced from the carbon which it contains by this formula:

$$P = 14,580 (1-a-b).$$

According to the analysis of M. de Marsilly, dry coke contains on the average 4 per cent. hydrogen and 6 per cent. of ashes. For a coke containing 2 per cent of water and 10 per cent of ashes the proportion of hydrogen is reduced to .035.

 $P' = 14,580 \times 0.088 - 1009 (0.02 + 9 \times .035) = 12,512.$

ANTHRACITE.

This is the most brilliant of the coals; does not soil the fingers, and burns only at a high temperature. In America, and in Galle, where it is abundant and of good quality, it is employed in blast furnaces and for heating boilers. The anthracite coals of France are not very abundant, they crackle in the fire, and are useless for the

purposes to which they are put in other countries. They contain on the average about 4 per cent. of water and 4 per cent. of ash.

The calorific power of the pure fuel is from 14,760 to 15,840. A cubic foot weighs 112 lbs.

TABLE C.									
Nature of the fuel.	Wtr. pr ct	Ash pret		Calorific Power		Vol at 572°	Weight of steam at 90 lb. from		
	İ		P	P'	gas	0120-	practi'e		
Wood, dried to 252° Ordinary		2		7290	10.	21.	8.75		
wood Ordinary	30	2		4770	8.8	17.4	2.5		
tanbark Peat	48 25	12 8	9135	2539 5454	7.15 8.8	15. 18.5	.9 2.8		
(perfect)	8	10	12780	11110.8	11.0	23.	5.12		
Dry, with long flame Oily, with	4	8	14850	12600	14	29 4	6.5		
long flame Merchant	2 2	10 10		13820			3.85		
Olly (short flame)	ł	10		14508	16	34	7.1 7.84		
Ous h = .4 Anthracite	2 2	10		14040 15966	16.6 17.6		7.2 7.3		
Wood char- coal	6	4		12600	16	88.6			
Coke (good quality)		-		12438	17	86.	6.4		

The tables (C) give a resume of the theoretical calorific power P of pure fuels, and

of the actual calorific power of the fuel P', the deduction having been made from the latent heat of the water evaporated. In making an application of the average coefficient 6—10 (excepting in cases of tanbark, where the co-efficient is only 4—10) we obtain for the production of steam under the pressure of 90 lbs. to the square inch, about 1,179 calories, which are taken from the figures given in the last column. For oily coal with a long flame we have

 $\frac{13,320 \times 0.6}{-----} = 6.86 \text{ lbs.}$

These weights of water evaporated, to which we will return, are those which we accept in the ordinary usage from a boiler that is well built and set up, with an external firebox.

LIQUID FUELS.

These fuels comprise petroleum and coal oils. They are rarely employed in the production of steam under ordinary circumstances, but we will give their calorific power from the scientific standpoint, as determined by M. Sainte-Claire Deville.

Virginia and Pa. oils .81 to .88 18,360
Heavy oils (Paris gas) 1.044 16,020
Oils from the schists of
Autun and Pins 1.044 18,144

GASEOUS FUELS.

In foundries and blast furnaces the solid fuels are transformed into gaseous fuels under the influence of the air. In other cases these gases are obtained at the same time as the liquid fuels; that is, by the dis tillation of the fuel in closed vessels as in the case of illuminating gases. These gases are afterwards burned with a current of air in furnaces that are especially designed for them.

This mode of heating is only applied to the production of steam in the metallurgical works, as blast furnaces, etc. If it offers a better utilization of heat, it can only be used for continuous and regular work; it is therefore very inconvenient compared with the use of fuel upon grates, which allows the fire to be quickly banked in the evening, and to be started again in the morning. It is then only from a purely scientific standpoint that we give the calorific power of these gases.

Gas from a Lundin oven from wood sawdust containing 50 per cent. of water (Rinmann), 1823, calorific power; gas from peat having 18 per cent. water (Ebelmen), 1292: Siemens furnace from .75 oily coal, (Kraus), 1818; (Siemens) .25 dry coal, (Kraus), 1818;

blast furnace with wood charcoal, (Ebelmen—Bunsen), 1377; blast furnaces with coke, 1240; blast furnaces with crude oil, 2115; illuminating gas, water condensed, 20,322; illuminating gas density at 32 deg. = .52, water not condensed, 18,486.

VOLUME OF AIR NECESSARY FOR COMBUSTION.

Chemistry teaches us that one cubic foot of air contains 79 per cent of nitrogen and 21 per cent of oxygen. The density of oxygen is 1.43, and that of air is 1.293 at 32° Fahr., and under a pressure of 10 lbs. per sq. inch. Therefore

1 lb. of oxygen requires
$$\frac{1}{.92 \times 1.43}$$
 = 3.33

lbs. of air.

Carbonic acid containing 72.73 parts of oxygen and 27.27 parts of carbon requires

 $\frac{72.73}{27.27}$ = 2.667 lbs. of oxygen

or $2.667 \times 3.33 = 8.88$ lbs. of air at 32° Fahr.

Water being composed of 88.9 parts of oxygen and 11.1 of hydrogen shows that t burn one pound of hydrogen requires

$$\frac{80.9}{11.1} = 8 \text{ lbs. of oxygen}$$

or $8 \times 3.33 = 26.64$ lbs. of air at 32° Fahr

Knowing the quantity of carbon (C) and of free hydrogen (H) contained in one pound of the fuel, we can deduce the amount of air (V) necessary for its combustion.

We have $V = C \times 88.8 + 26.64 (H - \frac{9}{8})$

Example. For one pound of wood having 30 per cent of water and containing:

Carbon	0.35
Hydrogen	0.042
Oxygen and nitrogen	0.294
Water	0.3
Ashes	0.014
	0.294

the free hydrogen is $0.042 - \frac{}{8} = 0.005$.

(This ——- is taken because a portion of

the hydrogen goes to unite with the oxygen and therefore lessens the amount of air required by the hydrogen available for combustion. *Trans.*)

The volume of air required to burn this pound of wood will be $0.35 \times 8.88 + .005 \times 26.64 = 3.24$ lbs. of air.

For a dry coal containing 12 per cent of ashes and water or 0.88 of the pure fuel, we deduce from table (A) the average composition:

$$\begin{array}{lll} \textbf{Carbon} & 0.775 \times 0.88 = 0.682 \\ \textbf{Hydrogen} & 0.05 \times 0.88 = 0.044 \\ \textbf{Oxygen} & 0.175 \times 0.88 = 0.154 \\ \textbf{Water and ashes} & .12 \\ \end{array} \} 1 \ 000$$

The free hydrogen will therefore be

$$0.044 - \frac{0.154}{8} = 0.025$$

and the volume of air

 $0.682 \times 8.88 + 0.025 \times 26.64 = 6.72$ lbs.

In practice the volume of air required is from two to three times as great as that which we have specified; first, because the combustion is not perfect; second, because of the necessity of frequently opening the fire-box door.

According to Messrs. Scheurer-Kestner and Meunier, the maximum result from a fuel burned under steam boiler, is obtained when the excess of airreaches about thirty-three per cent. After combustion the vo-ume of the gas is the same as that of the air, since the carbonic acid has the same volume as the oxygen which formed it, but it is increased by the volume of steam formed by the water resulting from the combustion of the hydrogen. The volume of this steam or vapor is about six per cent. for wood and peat in a dry condition, and

about eight per cent. for the same, damp, and four per cent. for coal.

Table (C) contains the volumes of this gas (V) which is double the theoretical volume plus that of the vapor. Thus for the dry coal we have

$$V=2 \times 6.72 + 0.4 = 13.84$$
 lbs.

The volume of air in the table (C) is applied to furnaces having a free draft, and it is generally admitted that in case when the draft is forced either by an injector, ventilator or by a steam blower in the smoke stack, the volume of air that will be necessary (W) is from 6 to 7% of V, as we have already specified. Finally the total volume of gas V expanded to the temperature t of the chimney will give the volume V which ought to pass thus:

$$V' = V (1 + 0.00367 t)$$

for $t = 300^{\circ}$ is $V = V \times 1.55$
for $t = 570^{\circ}$ is $V = V \times 2.1$

COMBUSTION AND FIREBOXES.

We have seen that the carbon and hydrogen are the elements of combustion by means of which heat is obtained. Carbon is fixed (coke, and wood charcoal) or contained in the volatile hydrocarbons. Coke and wood charcoal constitute the solid

fuels that burn only upon the surface and are therefore luminous. The fuels containing the hydrocarbons are decomposed by heat and the combustible gases which are set free produce a flame which is only luminous upon that portion of its surface which is in contact with the air.

In dividing the fuels and the flame, we increased the surface of contact with air, so that the combustion is more rapid and more complete. The heat produced by the combustion of a body is dissipated; first, by the current which is generated about the body, and second, by radiation.

This power of radiation when considered in proportion to the total calorific power, is according to Peclet about twenty-five per cent for fuels that are burning with a flame and fifty per cent for glowing coals.

The following table gives the weight of oxygen and air necessary to burn 1 lb. of hydrogen or 1 lb. of carbon according as the latter is transformed into carbonic oxide (CO) or into carbonic acid (CO²), also the amount of heat set free, in which case reference is made to the first part of this section.

1 lb. of fuel.	Theoretical Oxygen.	Requirements.	Heat Produced
Hydrogen Carbon transf'med	8 lbs.	26.64 lbs.	62,028.
into {CO	1.333 2.666	4.44 8.88	4,451.4 14,580.
Difference			10,128.6 heat units.

At the commencement of combustion 1 lb. of carbon (C) unites with 2.666 lbs. of oxygen and forms 3.666 lbs. of carbonic acid (CO³), setting free 14,580 heat units. The volume of carbonic acid is the same as that of the air from which it was formed, but its density is greater; the combustion is then complete, but if the air is wanting in quantity, the 3.666 lbs. of carbonic acid (CO²) absorbs 1 lb. of carbon, forming 4,666 lbs. of carbonic oxide (CO). The heat set free by these 2 lbs. of carbon and transformed into carbonic acid is

 $2 \times 4451.4 = 8902.8$.

The loss resulting from the absorption of these 2lbs. of carbon is then

14,580-8902.8=5677.2 heat units.

If now we furnish these 4.666 lbs. of c rbonic oxide (CO) the oxygen which is necessary to complete this combustion, or 2.666 lbs., it will burn with a blue flame, and we shall have 7.333 carbonic acid (CO²); the heat set free will be

 $2 \times 10.128.6 = 20,257.2$

which added to the heat (CO) 8902.8 gives exactly $2 \times 14,580 = 29,160$ heat units. That is to say, the heat resulting from the complete combustion of 2 lbs. of carbon.

COMBUSTION OF THE HYDROCARBONS.

These gases, mixed with a sufficient quantity of air, burn with a blue flame, producing carbonic acid (CO2) and water like illuminating gas. For instance, if they are raised to a high temperature before they are mixed with air sufficient to effect their combustion, they are decomposed in their turn: the hydrogen burns first, and a part of the carbon is set free; this carbon then burns in its turn if it is in the presence of oxygen. and if the temperature of the mixture is sufficiently high. On the other hand, the combustion is incomplete and the carbon is set free, being held in suspension in the gas where it forms smoke, which, if it is cooled, is deposited in the shape of soot. SMOKE ONCE FORMED, CANNOT BE BURNED.

It is necessary then in order to avoid its production, to mix in the combustible gases a sufficient quantity of air at a high temperature in order that the combustion may be complete. This rule, simple as it is, has not yet been realized in practice, at least in the case of ordinary furnaces. In the gas works, to be sure, they have a kind of smoke consumer, but, as we have already stated, an apparatus like this is not usually adaptable to the regular and continuous use of ordinary practice.

It will be seen in a future number that the fire-box as arranged by Tenbrink, has given good results.

(For a description and cuts of this boiler, we refer the reader to the forthcoming matter on steam boilers by the same author. *Trans.*)

MANIPULATION OF THE FIRE.

We will only speak of the coal as the fuel in this connection.

We know that the gases resulting from combustion and the affluent air ought to be raised to, and maintained at a very high temperature, in order to obtain complete combustion. The turning back of the flames upon the bed or brickwork produces this mixture of gases, and gives us a combustion which is preferable to that which takes place when the gases rise vertically from the grate. This combustion should be com-

pleted in an open space or chamber called the combustion chamber, which may be a portion of the furnace space or connected with it. It is necessary then to avoid having the flames impinge directly upon the tubes where they are cooled, holding them there before their combustion is completed, depositing a large amount of soot and giving out more smoke. Often these combustible gases thus drawn through the tubes, burst intoflame when entering the chimney.

There has been a strenuous endeaver to raise these gases and suppress the smoke by the injection of steam or air, which is sometimes let in at the sides of the fire box, sometimes over the bed or by means of the door, in a continuous or in an intermittent way. We will not describe all of these advantages, partaking more or less of the character of smoke consumers, none of which have up to the present time been permanently successful.

An excess of air is preferable, for the loss of heat which results is less than that which results from incomplete combustion. A smoke burner needs an excess of air but it is not necessarily economical. The combustion would not be perfect and it will always have more or less smoke.

Skilful firemen could obtain the same economy as the best furnaces. The conclusions upon this subject are taken from Instructions Upon the Means of Preventing Smoke, drawn up by the Hygienic Council of the Seine, and from which we make the following quotations:

"The origin of smoke lies in the volatile products which are rapidly set free from most fuels; such as the different varieties of coal, peat, and wood when they are constantly exposed to an elevated temperature. These products are for the most part hydrocarbous which are themselves highly inflammable, and in order that they may burn two conditions are necessary. First, they must be mixed with the proper amount of air. Second, these mixtures must be raised to a high temperature. If these two conditions are not realized in the fire-box itself, or in the flues through which the gaseous products are led, the hydrocarbon undergoes a decomposition which results in abundant deposit of soot or carbon in finely attenuated particles which are drawn by the current of gas through the orifices to the chimney. When we throw upon a grate which is not really covered with incandescent coke, a considerable quantity of coal

so that it is covered to a total depth from eight to nine inches in thickness, the fresh particles of coal which find themselves in contact with the coke, undergo a rapid distillation: the temperature in the fire-box is suddenly lowered, at the same time the passage of air through the grates and the bed of fuels is obstructed. Neither of the two conditions necessary for the burning of the carborate of hydrogen are realized, thus we see torrents of black smoke coming out of the chimney. The introduction of air in such circumstances by wav of the furnace door or by any other means opening directly over the coal, is without effect, because the temperature is insufficient to inflame the gaseous products. The smoke gradually decreases, and does so in proportion as the coal is converted into coke or the decomposed into the volatile parts, and as the air gains freer access through the fuel which has agglomerated into lumps. allowing larger intervals between the pieces. and as the temperature is again raised by the effects of the combustion. If before the distillation is completed, we stir up the mixture of coaland coke that is lying upon the grate, with a poker, we put portions of the coal which are not yet carbonized, in

contact with fragments of coke that are very hot. The distillation then becomes very rapid and is accompanied by the reappearance of smoke.

"Furnaces whose grates are somewhat extended, so that the charges of fuel only cover them in part, and where the bed can be kept thin, give out very little smoke, especially if the coal is fired in small quantities at a time and if the fireman takes the precaution to throw the coal on the front portion of the grate so that the gaseous products of distillation reach the flues in passing over the heated surface, which covers the back portion of the grate and thus allows a sufficient amount of air to pass up through it. The production of smoke is considerably increased by having the grates of too small dimensions in proportion to the quantity of fuel, which is burned upon them in a given time, and by a bad manipulation of the furnace on the part of the firemen, who do their work at too great intervals of time, or use too much fuel at one firing. It has also further increased, other influences being equal, when fuels containing large proportions of volatile gases are used, or to speak only of those which are the most oily and have the greatest tendency to coke, the dry coals of a few departments of the North in the neighborhood of Charleroi in Belgium give out only a little smoke infurnaces which are tolerably well constructed and have ordinary care and attendance. The coke gives none at all, but escapes through the chimneys of those furnaces which are fed with this fuel, as a colorless gas, taking a small quantity of ashes in an extremely attenuated condition. Coal containing little hydrocarbon gives very little smoke and offers a great advantage in not burning spontaneously when it is banked up in large quantities."

When a piece of coal, the size of a man's fist, is thrown into the fire-box, it brightens slowly in burning; the center remains unchanged up to the time when its combustion takes place. Care must be taken that the fire is only raked over at infrequent intervals, since the coal does not burn easily when the mass is being continually broken up and drawn across the grate.

The depth of coal upon the grate ought to be uniform and in proportion to the draft, and not less than four inches or more than six inches in depth. The fireman should arrange this matter by the flame, which should be white when the combustion is good. A red flame indicates an incomplete combustion because of too great thickness of the fuel bed. A fire should be replenished by throwing the coal upon those parts which are burning most brilliantly. large pieces ought to be broken up with a pick in the line of their cleavage in order that the pieces should not be crumbled: that is, small pieces should be thrown in a thin and uniform layer over the furnace when it is in full blast, and the fireman should avoid putting a too heavy bed upon the same places or where the fire is not burning brightly. When a plant has large grates, it is preferable to replenish the fire alternately upon each half of the grate. The combustion which will thus be obtained is far better than firing over the whole surface at once.

TESTS OF EVAPORATION.

The economic value of a plant as a whole, that is, the boiler and engine, results not only from the good utilization of the steam in the engine, but also from the evaporative power of the boiler. If, at the same time that the indicated or effective work is noted, the amount of water fed to the boiler is also measured as well as the weight of the fuel that is burned, we will have a real

basis for estimating the value of the plan, by the water and fuel consumed. We will thus have the evaporative power of the boiler, that is, the quality of the steam produced per pound of fuel.

The greatest evaporation per pound of fuel depends upon the quality of your fuel. the good proportions of the furnace and boiler, the condition under which they are kept, and last of all but by no means least, upon the ability of the fireman. Thus the results of evaporative tests cannot be compared with each other when they are made in the same fire box with different qualities of fuel or with the same fuel in different furnaces, even although they may be made in both cases by the same fireman. When tests are made for the reception of the plant and the nature of the fuel is specified, the builder determines the figures which he can guarantee, from the calorific power of the fuel itself, and arranges his furnaces to obtain the best combustion for it. On the other hand, when no fuel specification is made, he will employ that fuel which will produce the highest rate of evaporation.

From the commercial point of view of the production of steam, the best combus-

tion is that which will produce per pound of fuel the highest rate of evaporation at the same price. We will suppose that two kinds of coal are to be tried in the same fire box and under the same conditions. One ton of coal costing \$4, will evaporate say 13,000 lbs, of water, or

$$\frac{13,000}{4}$$
 = 3,250 lbs. of steam per \$1.

One ton of the other, costing \$3.20, will evaporate 10,000 lbs. of water, or

$$\frac{10,000}{3.2}$$
 = 3,125 lbs. of steam per \$1.

With these figures the dearest coal therefore is the most economical. If we are driving an engine of 100 H. P. consuming 20 lbs. of steam per H. P. per hour and working 300 days at ten hours each during the year, the expense will be, with the \$4 coal.

$$\frac{300 \times 10 \times 100 \times 20}{3.250} = \$1.846.15$$

With the coal at \$3.20

$$300 \times 10 \times 100 \times 20$$
 =\$1,920.

3125

The annual saving will therefore be \$73.85. Furthermore we will have 92.3 tons less to store, or at the rate of 7.7 tons per month. We can readily see, then, what importance these calculations assume when large industries are taken into consideration.

Tests of this kind have been made by M. P. Ducos, an engineer at Bordeaux, with English coal in regular usage, having a boiler with 1,063 squarefeet of heating surface and 32 square feet of grate. The pressure of the steam was taken at five atmospheres absolute, or at an effective pressure of 59 lbs., with feed water estimated on a basis of 32° F. The hydrometric conditions and the amount of ashes were determined in advance, but are not indicated by M. Ducos.

		Dwane		
Kind of coal.	Per ton ready for use.		Compared with Cardiff.	Evaporation per lb. of coal.
Cardiff Liverpool Newcastle Coke with 6 per cent of	8.0 2.6 2.9	3.888 4.876 5.261	3.0 2.36 2.2	7.816 5.832 5.507
water	2.8	5.259	2.2	5.324

TESTS OF EVAPORATION.

The Cardiff coal, although costing the

most, was therefore, in the case just cited, the most economical.

The firm of Decker & Co., of Cannstatt, (Wurtemburg), has obtained the following results under a battery of boilers with Tenbrink furnaces.

Kind of coal.	Per cent of ashes.	Coal per lb. of water evaporated.	Cost of coal per ton , 2240 lbs.)	Cost per 100 lbs. wa- ter evapora ted.	Evaporation per 1b.	Coal burned per sq. ft. grate surface.
Herne Bochum, Heinitz, 1st quality Izenplitz, 2d " Reden, 2d " Konig, 3d "	12.5 7.5 12.5 10.2 19.5	.1018 .1006 .1115 .109 .1882	\$4.87 4.76 8.82 3.99 3.10	.021 .019 .019	9.82 9.93 8.97 9.17 7.51	6.70 7.00 7.07

CONDUCTION OF THE TEST.

A test ought to be as prolonged as possible and to be made in the regular working of the plant, that is to say, some time after the fire has been started, in order that the loss of heat which occurs through the heating of the mason work should be that of regular practice. The test can be made without deranging the regular working conditions.

At the beginning of each operation the grates and fire should be carefully cleaned

and then an estimate made of the coal which is upon the grates; and it should be so arranged that there should be the same quantity left at the end of the test.

In general the total expense of the fuel is that which is burned during the test, plus that which remains upon the grate at the end, reduction having been made of that which was upon the grate at the beginning and of the coked portions which can be used from among the cinders.

The gauging of the water may be made first, by taking the dimensions and number of strokes of the supplying feed-pump; second, by a water meter; third, by automatic feeders which are also meters; and finally, by tilting gauges; this last alone should be employed for rigorous tests.

Care should be taken, as far as possible, that, at the end of the test, the water in the boiler should have the same level and the same steam pressure should exist as at the beginning. When this is not the case a correction should be made.

Correction:—It is necessary to ascertain accurately the level of the water in the boiler at the beginning and the end, for indications of the gauge-glass are not exact. In fact, the water has a lower temperature

in the glass than in the boiler. It is therefore more dense and its level is lower than in the latter.

If we open the cock at the bottom of the tube for a moment, the water which refills the tube will then have the same temperature and be at the same level as that of the boiler. It is necessary that this should be noted instantly, for the water is soon cooled and its level lowered. The difference in the levels h' Fig. 1, increases with the difference in temperature between h and h'; and

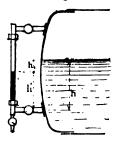


FIG. 1.

also with the length of the glass or of the level of h' above the lower connection, which is an important matter when the lower tube is screwed far down in the boiler.

If we take it for granted that the temperature of the water in a tube stands at 104 degrees, its co-efficient of expansion will be

.000259, and we obtain the following values for h^2 in inches, for the different temperatures per inch of height of water taken at the temperature of 32 degrees Fahr.; h' = h — h' = .000259 (t—104).

Absolute No. of atmospheres. Temperature t. Hs per in. of water at 32° Volume of water at 32°	1 212	.037	.048	.055	8 838 .06 .948	.065

Suppose then we have observed the exact level and the pressure before and after the test; the tables of Regnault which are appended give the corresponding temperatures.

(These tables will appear in a future number of this work.—Trans.)

The correction consists of collecting the number of calorics contained in the boiler before and after the test.

We calculate first the volume V, reduced to a temperature of 32 degrees. For a cubic foot which appears in the boiler at the temperature t, we have the formula:—

$$V = \frac{1}{1 + 0.000259} (t - 32)$$

(This 32 is the constant number to bring the temperature as read upon a Fahrenheit thermometer to the number of degrees above freezing. With the centigrade thermometer no such reduction is necessary. *Trans.*)

'The volumes are then indicated in the above table.

We then calculate the number of contained calories: 1st, in the weight of water thus corrected; 2nd, the calories in the metal, by taking the calorific capacity of the iron, for temperatures ranging from 32° Fahr. to 400° Fahr. as equal to .115 (Duong and Petit.)

We can then neglect the variation of heat contained in the steam itself as resulting from the effects of expansion.

Knowing the number of calories gained or lost by the boiler, we deduct the equivalent weight of fuel according to the mean amount of heat that has been utilized, at from 7,000 to 9,000 heat units per pound of coal. For example: In a boiler of 48 inches diameter and 50 feet long, we have ascertained after the trial that the water has lowered in its level four-tenths of an inch, and that the pressure has fallen from four to six atmospheres. The feed water being taken at 59°. From the size of this boiler we have

	Apparent Volume.	Pressure.	Temperature	t-59
Before the test.	4728 gal.	6 at.	819	947
After " "	4258 "	4 at.	291	919

The corrected volume at 32° Fahr. and the amount of heat will be:

Before: $4728 \times .947 = 4477.416$ gals. as the volume at 32° Fahr. Multiply by 8.33 as the weight of one gallon of water, we have $4477.416 \times 8.33 = 37,296.975$ lbs.; multiplying again by 247,

 $37,296.975 \times 247 = 9,212,352.5$ heat units.

Then after the test, following the same rule,

 $4253 \times .954 = 4057.362$ which $\times 8.33 = 33,797.825$, and this $\times 219 = 7,401,723.7$.

Then having 9,212,352.5, subtract 7,401,-723.7, leaving 1.810,628.8 heat units.

The boiler weighing 33,000 lbs. has lost 33,000 x.115 (319—291)=106,260 heat units.

The total loss of heat is equal to

1,810,628.8 106,260

^{1,916,888.8} heat units,

which represents at least $\frac{1,916,888.8}{7000} = 273.84 \text{ lbs. of coal.}$

Water in 1bs.	Coal in 1bs.
15,840 8,499	2,750. 278.84
19,889	8,028.64
	15,840 3,499

(The 3,499 lbs. is the difference in the weight of water before and after the test.)

The real evaporative efficiency per pound

of coal is then $\frac{19,339}{3023,84} = 6.4$ lbs. of water.

If the level of the water had been raised instead of lowered, the loss after rectification would have been taken from those that had been indicated during the test. A test made during the regular working of the plant will give an evaporative figure somewhat exaggerated, if the engine causes the boiler to prime, as frequently happens. There is no particular method of ascertaining the amount of water drawn off under these circumstances. It is shown in another portion of the work that the calorimetric system can be applied to this

case. (This test will appear in another volume of this work. Trans.)

Dry steam is colorless, and if we open a cock, the jet of steam will be invisible as it comes out, until it contains more than three to four per cent of water. As the jet leaves the cock, it assumes a cloudy appearance in consequence of the condensation of the steam. If, on the other hand, the steam contains a large percentage of water, it presents this cloudy appearance from the very start. When the tests are made while the plant is out of use, priming can be avoided by proceeding as follows: We run the engine very slowly under a light load, but rapidly enough and with sufficient regularity to require a regular supply of steam from the yet having it as light as possible. The surplus of steam furnished by the boiler is lost in the atmosphere by means of the safetyvalves. The water and fuel are measured as we have already indicated.

We have not spoken of the fuel that is burned while we are getting up steam. Its importance diminishes as the duration of the test is lengthened out. Nevertheless, it is necessary to take an account of it, if we compare the boilers of different systems; for instance a boiler holding a large volume of water, with one holding a small volume. The first will require upon the first day a considerable quantity of fuel in order to get up the pressure; but afterwards it will require very little on account of the heat which is stored up in its mass. The second apparatus, on the other hand, will require almost the same quantity each day. The comparison will only be correct then, if we take into account the whole amount of fuel that has been burned upon each day, and during the whole progress of the test.

We have said that we can measure the water fed into the boiler by means of a This meter can serve to control the manipulations of the boiler, just as a totalizing indicator controls the manipulations of the engine. In fact, in comparing the indications of the meter with those of the totalizer, and also with the fuel which is burned each day, we can make a correct statement of the amount of evaporation which has been performed, and of the importance which should be attached to priming, and also the amount of incrustation, if we continue our tests for a long enough time. This will be the best method of ascertaining the skill of the firemen.

THE CONTROL OF COMBUSTION.

The Orsat Apparatus.—Perfect combustion only takes place in the furnace and flues when the carbonic acid gas that has

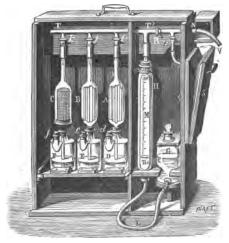


FIG 2

been formed has the same volume as the air which furnished the oxygen, plus that of the nitrogen. But, in reality, there is always a certain amount of carbonic oxide, whose volume is twice that of the air form-

ed, plus the oxygen taken from the air and not burned.

The Orsat apparatus is only another and modified form of the endiometer of Regnault and Schloesing, which has been so perfected by its maker, Salleron, that it permits those three gases, oxygen, carbonic oxide and carbonic acid, to be rapidly measured, and to deduce therefrom the amount of each (O, CO and CO²) by eliminating the amount of nitrogen; and consequently to learn what volume of air corresponds to one cubic foot of the gaseous mixture.

The apparatus is composed first of an aspirator of the gas (Fig. 2), G and M, serving to measure its volume at the beginning of the experiment, and after its absorption by each reacting agent; second, a series of three retorts (A, B, C) in which the absorption of each gas is successively effected by means of a suitable re-agent; third, a bellows S which has for its object the clearing of the conduit that puts the apparatus in communication with the reservoir of the gas that is to be analyzed.

G is a flask containing acidulated water; acidulated by hydro-chloric acid, which takes away from it the property of dissolv-

ing carbonic gas. This flask communicates by means of a rubber tube L with the lower part of the graduated tube M. which is called the measurer, and is itself enclosed in a glass casing filled with water in order that the measurements may all be taken at the same temperature. The upper end of the measure is connected with the horizontal tube T T, which is made of glass having the valve R, as well as the three vertical tubes which are furnished with the cocks i, j, k. These small tubes are connected in turn by means of rubber tubes attached to the upper extremities of the glass necks of the retorts A, B, C; while the lower necks are run down into a liquid contained in the flasks D, E, F. The joints of the different connections of the apparatus are hermetically sealed by means of wax and a fine brass wire. The openings, d, e, f, of the flasks are closed by rubber stoppers.

The apparatus is put into connection with the reservoir containing the gas to be analyzed by means of the rubber tube V which is attached to the end of the glass tube T. Finally a bellows S is attached to the outside of the casing and communicates with the glass tube through the cock r,



thus permitting it to extract the air from the conduit V.

In order to make the tests which we are to undertake, it is necessary to know the proportions of carbonic acid, carbonic oxide and oxygen which are contained in the gas. The re-agents are first, soda lye as absorbent of carbonic acid; second, a solution of pyro-gallate of potash as the absorbent of the oxygen; and third, an ammoniacal solution of the proto-chloride of copper to separate the carbonic oxide. The retorts A and B contain a large number of glass tubes which are wet with the solution in order to multiply the amount of surface which the re-agents can bring in coatact with the gas, and thus hasten the absorption.

C contains a quantity of red copper foil which, by being dissolved in the hydrochlorate of ammonia, produces the protochloride of copper, and the production of the re-agent. The pyrogallate of potash and the ammoniacal chloride of copper being absorbents of oxygen, it is necessary that care should be taken that the contents of the flasks E and F do not come in contact with the air. For this purpose we cover the liquid with a film of petroleum

oil about a twentieth of an inch in thickness. But it is necessary to take care in the manipulation that it does not pass into the retorts where the absorption takes place.

We now proceed to methods of the analysis itself. The cock R is opened in such a way as to put the apparatus in communication with the atmosphere. An aspirator Eis raised up; the acidulated water then runs down and fills the measurer completely, driving out the air which formerly was contained therein. We then close the cooks i and j and open the cock k, and take out the stopper f. In letting down the flask G we produce an inhalation of the air contained in the retort C, which is then filled with the liquid which was contained in the flask F. We raise the level of the liquid up to the mark which is cut upon the tube that runs from the top of the retort, then close the cock k. We then open the cock R, and raising the aspirator, we fill the measurer with water once again; then closing R, we open j, take out the stopper eand draw up into the retort B the liquid contained in the flask E. Repeating this same movement a third time, we cause the liquid that is contained in the flask D to

flow up into the retort A. We now open the cock R again, and then raise the aspirator in such a manner as to fill the measurer up to the upper mark indicating the zero point of the graduation. We close the cock R and then establish by means of the tube N, as shown in the engraving, the communication of the apparatus containing the gas that is to be analyzed. We open the cock r and operate the bellows, blowing into the tube V until it is freedfrom the air and gas which is left from the preceding operation. After a few moments, when we are certain that the conduit V is entirely filled with the gas which we are to analyze. then close the cock r and open the cock R. in such a way as to put the tubes T and Vinto communication, and to isolate the bel-The water flows into the aspirator until the measuring tube is full of gas, and when it is at the same level in both, we close the cock R so as to separate the apparatus from the conduit and the bellows. we examine to see that the gas, which we are going to analyze, occupies just one hundredth part of the graduated tube M. We open the cock i and close the flask G: the water drives the gas into the retort A which contains the soda lye, the nest of glass



tubes multiplying the surfaces of contact. and the carbonic acid is absorbed; we lower the aspirator and the gas again fills the measurer, and the retort A is filled with the lye: we force it up until it reaches the mark put upon the glass, and then close the cock i. We place the flask G in such a manner that the water which it contains will be upon the same level as that of the measurer, in order that the gas which is there contained may be subjected to atmospheric pressure alone. We then read the volume occupied and the difference between the reading made before the absorption, and that which is made afterwards, gives the volume of carbonic acid gas which has been retained by the soda.

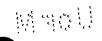
We open the cock j, and, operating in precisely the same manner with the retort B, which contains the solution of pyro-gallate of potash, we ascertain the volume of oxygen absorbed. Finally we repeat the same manipulation with the retort C, which was filled with a solution of the ammoniacal proto-chloride of copper, and obtain in the same manner the volume of carbonic oxide.

If, after these three absorptions, any gas remains, its volume represents the nitrogen which can not be absorbed by any of the re-agents which we have been using. In order that the absorption may be complete, it is absolutely necessary to wash the gas several times in each retort. We do not proceed from one washing to another until two consecutive readings are identical.

The absorption of the carbonic acid is more rapid as the concentration of the lye is greater. It is necessary then to replenish the liquid in the flask, and when the reaction becomes too slow, that is to say, when the greater part of the alkali has been transformed into a carbonate. The solution of the potash has the same concentration as that of the sods. It is best to add the pyro-gallate acid just at the time when the experiment is to be made, and in proportion to the quantity and volume of the oxygen which we anticipate it will be necessary to absorb.

The ammoniacal proto-chloride of copper is obtained by the dissolving of the copper foil in a liquid formed by two-thirds of a solution of hydro-chlorate of ammonia and one-third of ordinary ammonia at a temperature of 72 degrees.

The proto-chloride of copper has the property of absorbing oxygen also. In order that the last reaction indicated may



exactly represent the carbonic acid, it is necessary then that no oxygen should remain unabsorbed by the pyro-gallate of potash. The production of the proto-chloride of copper is somewhat slow. It is sometimes advantageous to replace this product by proto-chloric acid, which also has the property of absorbing carbonic oxide. We find this in the form of a crystalized salt upon the market, but is partially altered by contact with the air. We therefore put it into the flask F, where we dissolve it in hydro-chloric acid, and in order to bring it into the proto-chloride state, we add a few pieces of copper turnings. The liquid, which is at first brown, becomes discolored. We keep it under a film of petroleum. as we have already indicated above.

If we are working with one hundred volumes of gas, and if

x =the volume of nitrogen.

y = the oxygen and carbonic acid gas,

z =the carbonic oxide,

we will have

$$x+y+z = 100;$$
and $\frac{x}{y+\frac{z}{2}} = \frac{79}{21}$

Replacing y by its value taken from the first equation, we have

$$100 x = 7,900 - 79 \frac{z}{2}$$

from which z may be obtained when x has been found by analysis.

(THE END.)